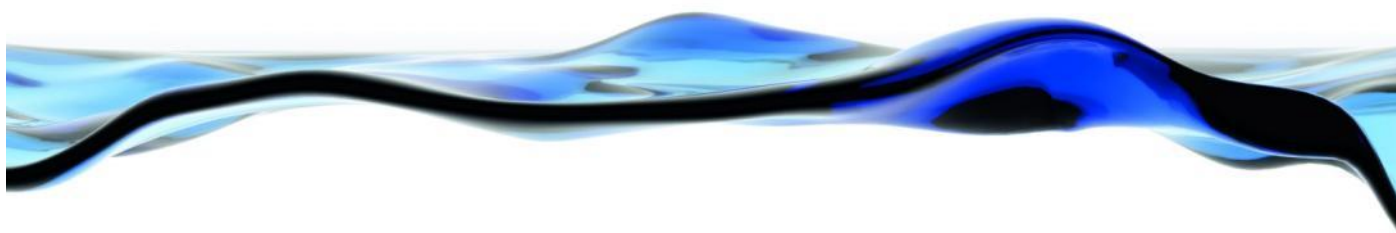


Extending the water quality modelling capability within eWater Source – developing the dSedNet plugin

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Table of contents

Terminology	1
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Executive summary

Key activities undertaken.....	1
The software	1
The Source Onkaparinga model.....	2
Baseline and trial results.....	2
Benefits	2
Next steps	3
Ongoing use in Mt Lofty catchment	3
Development of the dSedNet plugin	3

1 Introduction

1.1	Short description of dSedNet	5
1.2	Rationale for this research activity	5
1.3	SedNET development history	6
1.4	SedNet structure.....	8
1.5	Audience for this report	8
1.6	Companion documents	9
1.7	Acknowledgements	10

2 Scope of the work

2.1	Approach and rationale	11
2.2	Source development principles	12
2.2.1	Core	13
2.2.2	Plugin	14
2.2.3	eWater Source practices	14
2.3	Access and licensing	14
2.4	Source releases	15
2.5	Training and handover.....	15

3 dSedNet plugin

3.1	Hillslope erosion component model	16
3.2	Gully erosion component model	17
3.3	dSedNet scenarios	17
3.3.1	Setting up a dSedNet Scenario in Source	18

3.4	Spatial parameterisation	19
3.4.1	Using the spatial parameteriser	21
3.5	Temporal parameterisation.....	25
3.5.1	Using the temporal parameteriser	25

4 Trial of dSedNet plugin in the Onkaparinga catchment

4.1	Trial strategy	26
4.2	Study area	27
4.3	Source Catchments implementation	29
4.4	dSedNet parameterisation	31
4.5	Baseline.....	32
4.6	Trial results	35
4.6.1	Against SedNet sediment budgets (Wilkinson et al. 2005).....	35
4.6.2	Simulated loads against EMC/DWC loads (Fleming et al. 2010).....	35
4.6.3	Against statistically derived loads (Kuhnert et al. 2015).....	37
4.6.4	Against observed	39

5 Benefits of the approach

6 Next steps

6.1	Ongoing use in Mt Lofty catchment	42
6.1.1	Calibration of the hillslope and gully models	42
6.1.2	Using existing particle size data to establish sediment fraction (fine vs coarse) 42	
6.1.3	Using local sediment deposition data	42
6.1.4	Running scenarios	43
6.2	Ongoing development of the dSedNet plugin.....	43
6.2.1	Peer review of the gully and hillslope model code	43
6.2.2	Completing the dSedNet plugin	43
6.3	Reflections	44

7 References

Appendix A Constituent Sources

A.1	Overview	47
A.2	Editing, adding and removing Constituent Sources	47
A.3	Editing, adding and removing Constituent Sources from Functional Units	48
A.4	Constituent model linking	52
A.5	Constituent model configuration import/export and copy/paste	53

List of Figures

Figure 1, SedNet development timeline	7
Figure 2, Schematic representation of the dynamic SedNET component module linkages for cropping lands in central and northern Queensland (Source: Ellis & Searle, 2014)	9
Figure 3, Simple plugin architecture	13
Figure 4, Erosion model component modules (from Wilkinson et al, 2014, Figure 2)	16
Figure 5, Map representation of the functionality provided by the spatial parameteriser	20
Figure 6, Schematic of the functionality provided by the spatial parameteriser	21
Figure 7, Spatial parameteriser dialog, using the gully erosion model as the example	22
Figure 8, Constituent model configuration.....	24
Figure 9, Map showing the location of modelled Onkaparinga catchment	28
Figure 10, Node-link diagram of the Source model conceptualisation of the modelled Onkaparinga catchments	29
Figure 11, Observed rainfall and streamflow for the Onkaparinga River at Houlgraves Weir (A5030504) for the period 1991 to 2013	30
Figure 12, Rainfall, observed and simulated flow at Houlgraves Weir in August 2004	32
Figure 13, Plot of observed flow vs observed TSS concentration at Houlgraves Weir (A5030504)	33
Figure 14, Simulated (top) coarse and (bottom) fine sediment concentration (mg/L) vs simulated flow rate (GL/day) at Houlgraves Weir (A5030504).....	34
Figure 15, Annual simulated sediment loads from dSedNet and EMC/DWC approach at Houlgraves Weir for the period 1980 to 2013 with Gully Daily Runoff Power factor of (top) 1.0 and (bottom) 5.0	37
Figure 16, dSedNet (coarse and fine) simulated daily sediment loads and Loads Regression Estimator (LRE, Total) load estimates	38
Figure 17, dSedNet simulated sediment loads and observed TSS data. Note that the plot also includes simulated load from the EMC/DWC approach (TSS(EMC))	39
Figure 18, Constituents Configuration screen (Constituent Sources editor on right)	48
Figure 19, Constituent Model Configuration screen	49
Figure 20, Assigning a new Constituent Source to a Constituent / FU	50
Figure 21, Shows two Constituent Sources for FU1. Gully with an EMC/DWC model and Hill with none	51
Figure 22, Shows the linkage column “quickflowSedimentIn” for the NDR filter model w/tooltip shown.....	52
Figure 23, Define Constituent Model Linkage dialog.....	53

List of Tables

Table 1, Terminology	1
Table 2, High-level software development components (areas, functions, components) showing those components that have been completed as part of this project (indicated by ✓ in Status column)	11
Table 3, Data requirements for the hillslope erosion model.....	17
Table 4, Data requirements for the gully erosion model.....	17
Table 5, The result from parameterising a model that exists only for landuses B and C	20

Table 6, Gully erosion model parameters that require a value before executing the temporal parameteriser	25
Table 7, Hillslope and gully erosion model parameters that are assigned by the temporal parameteriser	25
Table 8, Landuses in the catchment area contributing to Houlgraves Weir	30
Table 9, Description of input data and values used in Wilkinson et al. (2014) and this trial. 'Equation' (column 3) identifies the equation in Wilkinson et al. (2014)	31
Table 10, dSedNet predicted mean annual load (kTonnes) to Houlgraves Weir over the period 1/1/1980 to 3/12/2013 (34 years), for both the multi- and single-region hydrological calibrations	33
Table 11, SedNet annual sediment budgets from Table 4, Wilkinson et al. (2005)(Load kT/yr) and dSedNet multi-and single-region runs.....	35
Table 12, SIMHYD parameters and their description	55
Table 13, SIMHYD parameter values for subcatchments above Houlgraves Weir	55

Terminology

In writing this report, we have found a range of terms used to describe the component 'parts'. Other terms are commonly used in Source. These terms, with short descriptions, are listed in Table 1.

Table 1, Terminology

Term	Description
component	Similar to module – the component parts
constituent	A part of a whole e.g. sediments, total phosphorus, and total nitrogen are the constituents of dSedNet. This term is often used in preference to 'contaminant' as it is neutral
Core	The term used to refer to code that is written as integral to the Source code base. It is further described in Section 2.2.1
functional unit	(Source) areas that describe and contain a land use type
link	linkage between nodes and where routing and flow models are configured
model	Traditional concept of a model – code that describes a process or a relationship - has inputs, state variables, outputs, etc. An example from SedNet - the process of describing how gully erosion occurs is contained within the gully erosion model
module	Separate parts that are used to construct a more complex structure – each module performs a defined task and can be linked with other such parts to form a larger system. Models are implemented as modules within SedNet
node	Points of entry to the river system network
persistence	saving information/data to disk for later use
platform	Source is often referred to as a platform as it has been designed as a system on which other application programs can run.
plugin	This term refers to a code that is compiled separately to the Source codebase, but registered into Source at runtime. It is further described in Section 2.2.2

Executive summary

The catchments of the Mt Lofty Ranges (MLR) are a primary source of potable water to Adelaide and its environs. Because the catchments are mixed land uses (e.g. horticulture, grazing, hobby farms), the water exiting the catchments is not pristine and many studies have been undertaken to identify and quantify (through measurement and prediction) the sources of constituents, especially total suspended sediment (TSS), total phosphorus (TP) and total nitrogen (TN). Several models that describe the hydrology and related constituent generation and transport through these sub-catchments have been developed, the most recent using the eWater Source® platform. These studies, and models development, have highlighted constituent modelling as one of the issues requiring further work. It was considered that the Source model, as implemented at that time, predicted TN loads in the MLR quite well at longer timescales – however TP and TSS were generally underestimated in high rainfall years and overestimated in low rainfall years. The Event Mean Concentration (EMC) and Dry Weather Concentrations (DWC) approach used in Source was the major factor contributing to the poor representation of inter-annual variability of flow, due to the limited response to flow inherent in this model structure.

Key activities undertaken

To improve the parameterisation and methods used in Source for modelling constituents, the Goyder Institute for Water Research invested in extending the SedNet dynamic modelling capability through its Project I.1.7. This was primarily a software development exercise, using the Source model already developed for the catchments of the MLR. Three key activities were undertaken:

- The development of a spatial parameterisation tool to enable the rapid set-up of dSedNet models
- The development of two component modules of the dSedNet plugin – the hillslope and gully sediment generation models
- Trialling of the dSedNet plugin in the Onkaparinga catchment (Houlgraves Weir).

The development of the dSedNet plugin and spatial parameterisation tool has been the main activity within the project. Testing of the plugin was performed by running a series of small modelling trials. In addition to testing the robustness of the code, these trials provided an opportunity to consider the advantages of the dSedNet approach.

The software

The dSedNet software is being developed as a Source plugin; the spatial parameterisation tool has been developed within the core of Source platform. Plugins are easily distributed

between modellers and models, while changes to Source core are more difficult to manage as they require quality assurance by eWater and need to fit in with Source development and release cycles. This is advantageous from a maintenance perspective, but does reduce the control that the project team has over its release. At this point, a release date is unknown. The South Australian project team has a version of Source that contains the spatial parameterisation tool, and the dSedNet plugin, and a training workshop was held in May 2015.

The Source Onkaparinga model

The MLR Source model was modified to use the dSedNet plugin, with some parameters changed to match those used in other studies (such as Wilkinson et al. 2014). This is referred as the baseline, noting that it has not been calibrated against observed water quality data.

Additionally, two calibrations (multi- and single-region) of the rainfall-runoff model (SIMHYD), as described in Kuhnert et al. (2015), were used, giving two sets of results. The multi-region simulation used separate SIMHYD parameters for each region, according to the calibration of its gauge. The single-region calibration treated all sub-catchments as a single region, i.e. they all had the same SIMHYD parameters. The need to do this emerged during the trials to more closely match the hydrology to other studies and demonstrates the importance of using good hydrological models for constituent modelling.

Baseline and trial results

The Onkaparinga catchment was chosen for the trials, using observations at Houlgraves Weir. Three trials were conducted against previous studies: (i) SedNet sediment budgets Wilkinson et al. (2005), (ii) existing EMC/DWC Source model, and (iii) statistically derived loads by Kuhnert et al. (2015).

Simulations were run for the two rainfall-runoff calibrations (multi- and single-region), resulting in predicted (potential) loads of 15.9 and 19.5 kTonnes/year. This compared well with the 15.0 kTonnes/year predicted using SedNet and as reported in the Wilkinson et al. (2005) study, noting that this model was also uncalibrated. The trial against the EMC/DWC approach looked at temporal patterns and the role of parameter settings and the fact that dSedNet has many adjustable parameters that are not available in an EMC/DWC model. The trial against the statistically derived loads highlighted the power of dSedNet being able to incorporate spatial and temporal variation into model inputs. Simulated dSedNet loads tended to follow observed loads.

Benefits

As a spatially distributed model, dSedNet keeps track of spatial input data so that outputs can be traced back to their source. This is invaluable for targeting catchment remedial and

intervention activities, and is not available in the current EMC/DWC model. Moving to a daily (dSedNet) from an annual (SedNet) time-step has been a significant scientific endeavour dSedNet that supports modelling of the temporal dynamics of constituents in a catchment. This supports the ability to anticipate specific events (e.g. impacts of a large flow) at different times within a year and investigate within-year variations.

Operationalising dSedNet within Australia's national hydrological modelling platform (eWater's Source) provides researchers, planners and catchment managers with an integrated tool to explore the impacts on the quality of receiving waters of catchment dynamics, such as gully and riparian management, urban and agricultural intensification, and environmental flows.

Next steps

Ongoing use in Mt Lofty catchment

The MLR provide a unique opportunity to test and progress dSedNet, primarily due to the richness of the excellent water flow and quality dataset. This dataset is probably unparalleled in Australian catchments which have Source models. The current models need to be calibrated (and better parameterised) against these data.

Knowing sediment fraction (coarse vs fine) is important in sediment modelling. This is presently estimated from analysing multiple soil properties. A desktop study is proposed that would investigate the opportunity for using TSS as a surrogate for sediment fractions using existing particle size data from samples which have been analysed for TSS.

There is no comprehensive information available on sediment generation, transport and deposition in the MLR. A desktop study to investigate the use of currently available data, such as sedimentation basins (known sediment volumes), is proposed as an alternative to costly field studies.

The project team, which includes members of key stakeholder organisations such as the EPA and SA Water, is keen to continue with the dSedNet development, including the design and running of land use/management change scenarios.

Development of the dSedNet plugin

Firstly, the trials that were conducted in the project were not designed to fully test the product. In addition to a more rigorous testing phase, we recommend that the code undergo peer review. This is not a trivial exercise, but dSedNet is an important piece of work and warrants such an investment. This would benefit the existing code and any further developments.

This project has made a significant contribution to the development of dSedNet, but there is a large body of work still to be done. This includes coding the other generation and deposition models, and extending to constituents other than sediment (firstly total

phosphorus and total nitrogen). CSIRO does have a high level workplan which could be developed into a fully tasked project plan. CSIRO is actively looking for opportunities to fund this ongoing development and build the dSedNet community.

1 Introduction

This report describes the contribution made by the Goyder project I.1.7 to the development of the dSedNet plugin – a dynamic version of the SedNET erosion model (Wilkinson et al, 2014) implemented to run seamlessly within eWater's Source® catchments platform. The report includes an overview of the software development process (rationale for approach, method and implementation) and how to use the product (access and licensing, data requirements, running the tool, setting up scenarios).

The report concludes with a section that describes testing of the plugin using data from the Onkaparinga catchment of the Mt Lofty Ranges and recommendations for future work.

1.1 Short description of dSedNet

dSedNet is an implementation of dynamic SedNET – a time-stepping spatially-distributed sediment budget model for predicting daily sediment loads in river basins; and is based on a link-node representation of a hydrologically calibrated river system network. For each link in that network, the model constructs daily budgets (source and deposition) of fine and coarse sediment. These are accumulated to catchment outlet. Erosion rates (hillslope, gully and streambank) and fine sediment sinks (floodplains and reservoirs) are disaggregated from mean annual rates, based on daily rainfall and runoff. The model as a stand-alone module has been evaluated in the Burdekin basin in tropical Australia (Wilkinson et al, 2013), with promising results. The modelling approach is well described in Wilkinson et al. (2014).

The dSedNet plugin is an extension to the existing behaviours and usage of Source platform. The constituent generation models are implemented in the same way as the existing Source models are, with the addition of enhanced parameterisation functionality. The Spatial parameteriser built as part of this project and described in this report is independent to dSedNet and can be used to parameterise other types of models. In contrast, the temporal parameterisers built as part of this project are only for use with specific dSedNet components.

1.2 Rationale for this research activity

The catchments of the Mt Lofty Ranges (MLR) are a primary source of potable water to Adelaide and its environs. Thus the quality of that water is important. Because the catchments are mixed land uses (e.g. horticulture, grazing, hobby farms), the water exiting the catchments is not pristine and many studies have been undertaken to identify and quantify (through measurement and prediction) the sources of constituents, especially total suspended sediment (TSS), total phosphorus (TP) and total nitrogen (TN). Several models that describe the hydrology and related constituent generation and transport through these sub-catchments have been developed, the most recent using the eWater Source® platform.

Aspects of the development and calibration of this model are described in Fleming et al. (2010), Thomas et al. (2010) and Fleming et al. (2012).

Thomas et al. (2010) described how an improved Source model may support natural resource management (NRM) planning and policy initiatives in the MLR, and highlighted constituent modelling as one of the issues requiring further work. It was considered that the Source model, as implemented at that time, predicted TN loads in the MLR quite well – however TP and TSS were generally underestimated in high rainfall years and overestimated in low rainfall years (Thomas *pers comm*). The Event Mean Concentration (EMC) and Dry Weather Concentrations (DWC) approach used in Source for the MLR (Fleming et al. 2010) was thought to be the major factor contributing to the poor predictions.

To build on the investments made to date, and improve the parameterisation and methods used in Source for modelling constituents, the Goyder Institute for Water Research invested in extending the SedNet modelling capability through its Project I.1.7. The final agreed set of tasks were:

- **Development of architecture required to build N and P Source Plugins:** Develop Source core code to allow the spatial and temporal parameterisation of TSS, N and P models, necessary to retain spatial variability within the models.
- **Development of TSS Source Plugin:** Develop Source Plugins for daily TSS that can be amended to accommodate the various land uses in the Mt Lofty Ranges (e.g. horticulture, viticulture).
- **Model testing:** Parameterise and test the Source model for TSS, and calibrate the underlying hydrological model.

1.3 SedNET development history

The “Sediment River Network Model” (SedNet) was initially developed by Prosser et al. (2001) for the National Land and Water Resources Audit (NLWRA). It was a suite of Environmental Systems Research Institute (ESRI) ArcInfo programs that defined a river network and its contributing catchments, handled data and implemented the model. From this initial implementation, the concept and the application evolved to meet further requirements of modelling capability and usability.

The next implementation was a major re-write extended to include linkage of pollutant models to other aspects of the catchment. This was written in the same codebase used to develop Source (C#.NET and TIME¹) and made available through the Catchment Modelling Toolkit².

¹ TIME – The Invisible Modelling Environment. For details, the reader is referred to Rahman et al. (2003)

² eWater Catchment Modelling Toolkit: <http://toolkit.ewater.com.au/Tools/SedNet>

Specifications for a dynamic version of SedNET were then developed by eWater partners over the period 2009 to 2012 and published as an internal eWater CRC document. These specifications were designed to address the limitations of the simple EMC/DWC approach for simulating the effects of future management scenarios, including land use change.

The subsequent implementation (Dynamic Sednet) was by the Queensland government for their 'Paddock to Reef Modelling and Monitoring Program' towards meeting the Reef Water Quality Protection Plan (load) targets (Ellis et al. 2013, 2014; Wilkinson et al. 2014). This plugin is in-house and not publicly available; and was not developed against the most recent constituent modelling architecture. As described in the Introduction to Ellis and Searle (2014), there were several instances where the desired concept was unable to be applied or tested adequately, noting that the catchments were generally data poor and very large.

The development of the SedNet (dSedNet) plugin reported herein is the only current dSedNet development activity. However the methods have and continue to be tested in the Great Barrier Reef catchment project, e.g. the bed material sediment component by CSIRO and others.

The SedNet development lineage is captured in Figure 1.

Version	Style	Time step	Year															
			0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0	1 1	1 2	1 3	1 4	1 5	1 6
ArcInfo (CSIRO)	Standalone	Annual																
Toolkit (eWater)	Standalone	Annual																
Dynamic SedNet (eWater)	Specs	Daily																
Dynamic SedNet (Qld)	Plugin	Daily																
dSedNet (Goyder)	Plugin	Daily																
dSedNet (???)	Plugin	Daily																

Figure 1, SedNet development timeline

1.4 SedNet structure

SedNET can be thought of as a suite of component modules – each source and sink has its own model – these are assigned to Source’s integrating framework (see [eWater’s Source – Basic Concepts](#)³). Source’s integrating framework is a simple conceptual model of the real world and is made up of Catchments, Sub-catchments, Functional Units (FUs, e.g. areas defining landuse types), Nodes (points of entry to the river network) and Links (linkage between nodes and where routing and flow models are configured). Sednet constituent generation models are assigned to Functional Units, their outputs are passed through the in-stream processing modules, and then to the export load modules (for sediment and other constituents that are being modelled). All component modules do not need to be present to run SedNet – in fact some may not even be relevant for some catchments. For example, the gully module would not be required for a catchment without gullies, and the floodplain module would not be required for a catchment in which the river does not overbank and deposit sediment on its connected floodplain.

Figure 2 is a schematic representation prepared by the Qld government team that describes how they have built dynamic SedNet for cropped lands in the catchments that drain to the Great Barrier Reef. This diagram illustrates the size of dynamic SedNet (there are different schematics for sugar lands and grazing).

The dSedNet implementation is somewhat different to avoid this level of complexity. Nevertheless, a full implementation will have a similar structure. In this project, we have concentrated on the coarse and fine sediment generation from hillslopes and gullies as these were identified as the key erosion processes in the case study region.

1.5 Audience for this report

The main audience for this report are those people and organisations who are involved in or wish to do a comprehensive assessment of sediment transport from a catchment to surface water bodies. This includes the South Australian Source modelling community, in particular those engaged in the MLR modelling; and those planners and managers who wish to use eWater Source with the dSedNet plugin. It extends to modelling colleagues in other parts of Australia, ie all those who would be interested in using the plugin.

A secondary purpose is to provide one reference point for the activities conducted within the SedNet component of the project I.1.7.

As a legacy document, it is intended to be sufficient to inform the further development of the dSedNet plugin.

³ <https://ewater.atlassian.net/wiki/display/SD41/Basic+Concepts>

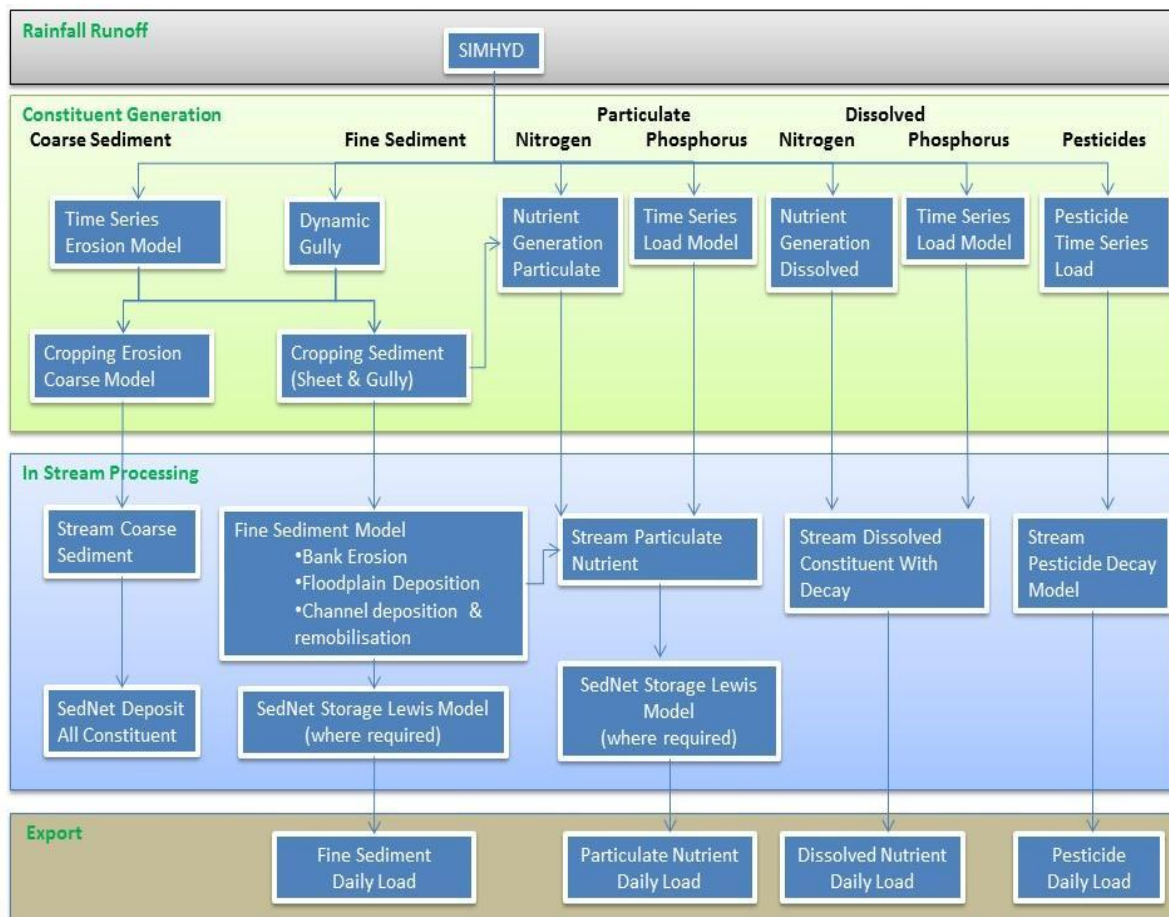


Figure 2, Schematic representation of the dynamic SedNET component module linkages for cropping lands in central and northern Queensland (Source: Ellis & Searle, 2014)

1.6 Companion documents

The larger report from the Project I.1.7 is 'An Improved Water Quality Model for South Australian Catchments' by Kuhnert et al. (2015) that describes an alternative statistical approach to predicting the quality of the water and how it may change under a (small) number of scenarios. That report is published in the Goyder Institute Technical Report series.

There will also be documentation accompanying the plugin and the Spatial and Temporal parameterisers when they are included in a future Source release. These documents need to conform to eWater specifications and are under preparation at the time of writing this report.

Text describing the revisions to the Source constituent modelling architecture is included in this report as it has not been published elsewhere. This development, including the documentation, was undertaken and funded by CSIRO in 2013/14. The work described in this report could not have been undertaken without this earlier piece of work.

1.7 Acknowledgements

This report would not have been possible, indeed the project and the outcomes achieved would not have been possible, without the commitment of all members of the project team, especially those agency staff whose time to the project was in-kind. We would like to thank them for their good will and camaraderie.

We would like to acknowledge and thank Petra Kuhnert and Dan Pagendam for their role in developing the companion statistical modelling approach as an adjunct to the work described in this report. This work grew when it was apparent that a full implementation of dSedNet was not realistic within such a small project. We would also like to thank Petra and Dan for their leadership – Petra up until March, and then Dan through to the end of June 2015.

People who assisted in shaping the project and the implementation described herein, and worthy of special mention are Ross Searle, Arthur Read and Scott Wilkinson (CSIRO), Clive Jenkins and Shaun Thomas (SA EPA) and Jacqueline Frizenschaf (SA Water).

From an implementation perspective, the Queensland government, through the development of their dynamic SedNet, paved the way for dSedNet. They have kindly made their code, documentation and advice available to us and we thank them, in particular Robin Ellis and Paul Lawrence.

Reviewing is critical and also time-consuming and we would like to acknowledge the thorough reviewing provided by CSIRO and DEWNR colleagues.

Last, but not least, the funding support provided by the South Australian Government, the CSIRO, SA EPA, SARDI, DEWNR and SA Water through the Goyder Institute for Water Research is gratefully acknowledged. All organisations have made significant in-kind contribution, over and above that detailed in the project budget.

2 Scope of the work

The EMC/DWC approach reported in Section 1, available in Source and implemented in the MLR Source model proved insufficient to support the exploration of NRM and land use/management planning and policy initiatives. Thus, it was agreed that a research project would be established to trial the dynamic SedNet approach to determine whether that approach would give better results.

This section describes the scope of the work that was developed to best meet the project objectives, within the resources of the project.

2.1 Approach and rationale

While not directly applicable to the MLR catchments, the dynamic SedNET plugin developed by the Queensland government (Ellis and Searle 2014) was identified as being able to provide direction in how to implement the dynamic SedNet specifications; and its codebase was kindly made available to the project team by the Queensland Government for reference. However, it was not directly applicable to the MLR catchments because of the differences in catchment characteristics, and its development over several years resulting in a gargantuan codebase, difficult to disassemble and then extend.

Two options were then available: (1) follow the Qld Govt approach of trial-and-error, leading to a highly tailored but not very scalable product; (2) adopt a longer-term community view and generalise the Dynamic SedNet plugin to take advantage of recent changes in the underlying architecture, and to make it more applicable to a broader set of users and applications. The 2nd option was taken.

The software development work for dSedNet can be broken down as shown in Table 2, with the Status column showing those functions that have been completed and/or released in the version of dSedNet available at the end of this project.

Table 2, High-level software development components (areas, functions, components) showing those components that have been completed as part of this project (indicated by ✓ in Status column)

Areas	Function	Components	Status*
Models	Constituent generation	Hillslope	✓
		Gully	✓
		Streambank	
		Nutrient (dissolved, particulate)	
	In-stream processing	Sediment (deposition)	
		Nutrient (deposition, decay)	

Areas	Function	Components	Status*
	Storage processing	Sediment (deposition)	
		Nutrient (deposition, decay)	
Parameterisation	Spatial parameterisation	Generation models	✓
	Temporal parameterisation	Generation models	✓
Configuration	Validation	Landuse area definition	✓
Plugin management	UI configuration	Main UI additions	✓
		Access to plugin functions	✓
	Persistence	Mapping data into a database or saving to a file	✓
Result visualisation	Statistics	Totals	
		Spatial contributions of sediment	
Quality management	Quality control	Unit testing of each component	✓
		Regression testing (components and the system)	✓

* Status identifies work completed a/o released in the first version of dSedNet (requiring further work as the system evolves)

In Table 2, User Interface (**UI**)**configuration** requires adding new menu items to the main menu system and linking them to the new functionality (Table 2); **Persistence** is the ability to save the model configuration and status to disk (or database); and **Testing** covers the testing of models and parameteriser behaviour so that it achieves what is expected and is not altered by changes over time.

As the work required to complete a full implementation (high level components listed in Table 2) was far greater than what could be accommodated within the current project, the work (development tasks) was prioritised to maximise functionality to meet the objectives of Project I.1.7, resulting in development of the **Hillslope** and **Gully** models, together with a **spatial parameteriser** to automate the populating of model input parameters from spatial data.

2.2 Source development principles

The code can be implemented within the 'Core' code of Source or as a Source 'Plugin'. The difference is extremely important from a release and maintenance perspective and is described below.

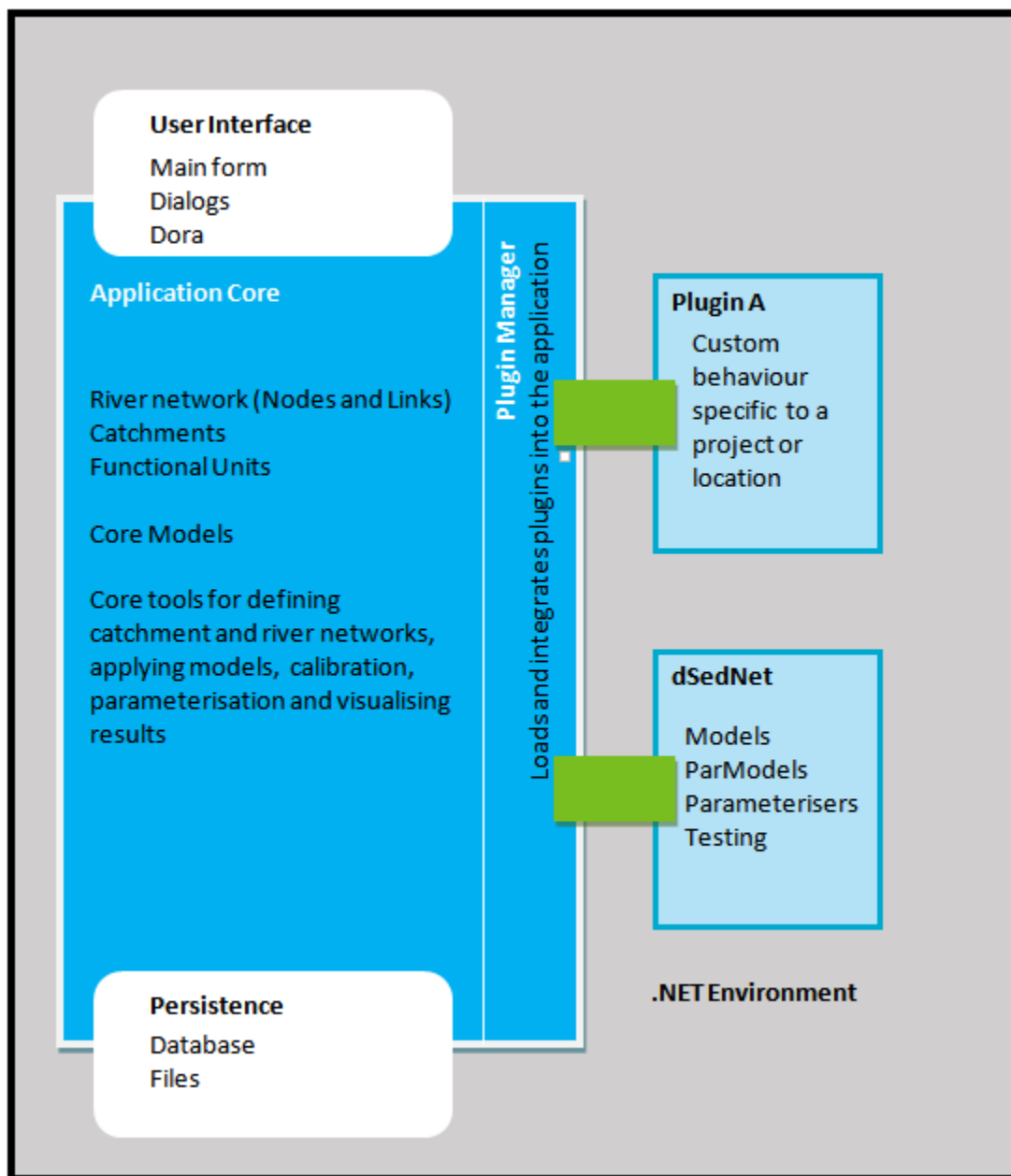


Figure 3, Simple plugin architecture

2.2.1 Core

After discussion with eWater, it was agreed that the spatial parameteriser would be part of the Core Source. This is a good outcome but with overheads. A key benefit is that the spatial parameteriser will be rolled out as part of Source and maintained by eWater – this ensures that it will always work in future releases of Source. An overhead is that development and testing cycles have to work in with eWater timelines and practices; and the dSedNet approach had to be generalised to meet Source Core philosophy (to be available and useful to multiple plugins and other parts of core Source). This resulted in a longer development time than anticipated.

The **spatial parameteriser** is in the Source Core.

2.2.2 Plugin

Work that is external to the Source application core but is able to be managed by Source and integrated into the way it functions is written as Source plugins. Plugin development can produce software elements that span across the Core's three main layers, UI (user interface), Domain (modelling framework) and Persistence (database). Plugins reside as external .dlls that are registered within Source.

The **hillslope** and **gully** erosion model modules are Source plugins.

2.2.3 eWater Source practices

'Core' development work must adhere to the development practices set by eWater. For example interface development must follow a pattern similar to the Model View View Model (MVVM) pattern. Code is peer reviewed, tested and reviewed by a domain expert (scientist). Documentation is written following their documentation guidelines. Once this work has been completed and accepted, then it becomes the responsibility of eWater to maintain this capability.

Plugin development groups like behaviour/capability to be assembled together in one package. Packaging capability like this allows for development of custom behaviours (e.g. MyTwistOnRainfallrunoff_Simhyd) which can be integrated into Source, extending or modifying its abilities. While quality is important, eWater allows more flexibility with plugins and they are developed to a standard set by the individual's organisation.

Specific capability of dSedNet only packages is only relevant to one set of modelling objectives – sediment and nutrient generation, deposition, decay and the parameterisation of these models. It is the responsibility of the developers of these packages to maintain them –ensuring their robustness, their compatibility with each Source release and that the user group have access to the plugin documentation and/or training needs for its use.

2.3 Access and licensing

As a community plugin, the dSedNet plugin will be distributed with all releases of Source. The accompanying User Guide will be available from eWater's Source Community of Practice web site⁴.

CSIRO retains the IP for the plugin, and acknowledges the contribution of the Queensland government in developing the dynamic SedNET plugin. Under the eWater Source community protocols, distribution of the product is through the community.

Documentation for the spatial parameteriser will be included with the eWater Source release.

⁴ <http://ewater.org.au/community/>

2.4 Source releases

It is assumed that SA EPA maintains the currency of their Source catchment model. CSIRO has eWater's agreement to provide an installer to SA EPA and SA Water for Source with the spatial parameteriser for the life of the project. When the tool passes eWater's quality assurance measures, it will be included in the next available release of Source (production version, beta). No date has been set by eWater.

The hillslope and gully erosion model plugins may be impacted by Source releases as there may be changes to Source that 'break' the connection with existing plugins (this is very normal in software engineering).

2.5 Training and handover

A workshop was held in Adelaide in late May to demonstrate the plugin. This was attended by the project team and other interested staff from SA Water and DEWNR.

3 dSedNet plugin

This section of the report provides high-level description of the erosion (hillslope and gully) models, and the spatial and temporal parameterisers used to parameterise the dSedNet models.

The section assumes that the reader has a reasonable knowledge and experience of Source and how to navigate through it; and a reasonable knowledge of how models are assigned and how their parameters are exposed through the user interface (UI). The following sections are not written as technical specifications or User Guides, but to document, at a relatively high level, their implementation and use. Please refer to Source's User Guide for more detailed information.

The hillslope and gully erosion models are two component modules of SedNet (Figure 4).

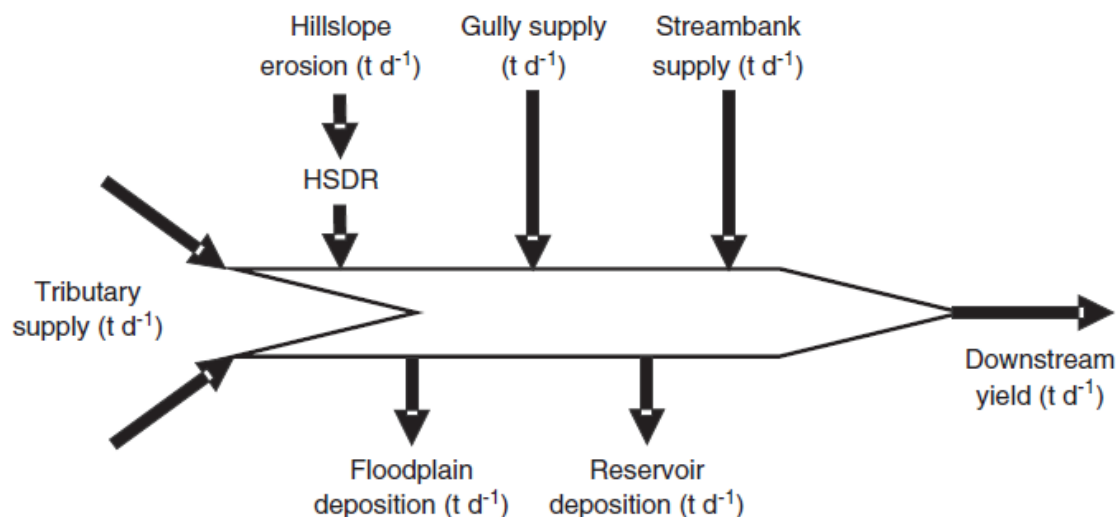


Figure 4, Erosion model component modules (from Wilkinson et al, 2014, Figure 2)

3.1 Hillslope erosion component model

“The fine sediment supplied from hillslopes in each FU to the stream network is the product of gross erosion rate, FU area and a hillslope sediment delivery ratio HSDR. Hillslope supply from each subcatchment is then the sum of the contributions from all FUs in the sub-catchment” (Wilkinson et al. 2014).

Gross daily hillslope erosion in each FU is estimated using the Modified Universal Soil Loss Equation (MUSLE) (parameters $R*K*L*S*C*P$), FU area is provided by Source, and HSDR is a ratio [0...1] set by the expert user (Table 3). A populated version of this table for the trial use case is available at Table 9.

Table 3, Data requirements for the hillslope erosion model

Parameter	Description
HSDR	hill sediment delivery ratio
R	rainfall erosivity factor
K	soil erodibility factor
L, S	slope length, gradient
C	cover factor
P	Practice factor

3.2 Gully erosion component model

“Gully erosion represents ongoing incision and enlargement of hillslope drainage lines and streams which have smaller contributing areas than the upstream extent of the model stream network. It also represents erosion of ‘badland’ areas of deep soil or alluvium (e.g. Brooks et al. 2009). Such erosion processes are usually caused by land use intensification” (Wilkinson et al. 2014).

An input map of the current areal density of gullies, their age and cross-section, together with relevant soil properties are used to calculate volume. Complete delivery to the stream network is assumed as shown in Table 4. A populated version of this table for the trial use case is available at Table 9.

Table 4, Data requirements for the gully erosion model

Parameter	Description
	Gully areal density
Pf	Proportion fine
Ps	Gully soil bulk density
aG	Gully cross-sectional area
LG	Gully length
T	Gully age (calculated from gully year of disturbance)
fG	Gully daily runoff power factor
Mg*	Management factor

* This factor is not yet implemented

3.3 dSedNet scenarios

The gully and hillslope (erosion) models provide some limited application of dSedNet for scenario analysis. These include:

- Hillslope model scenarios examples

- a base case current conditions scenario (C,R,K,L and S raster mapping required)
- effect of changes in rainfall/runoff (climate change?) (changes made to source model of runoff and C, R factor rasters)
- landuse changes that increase or reduce hillslope erosion (usually modelled through a change in cover factor rasters)
- management activities to reduce erosion (change to delivery parameter or cover factor rasters)
- changes in the seasonality of cover.
- Gully model scenarios examples
 - a base case current conditions scenario (raster gully density mapping required)
 - effect of changes in rainfall/runoff (climate change?) (changes made to source model of runoff and gully activity parameters)
 - land-use changes that increase or reduce gully density or activity (changes to input mapping or gully activity parameters)
 - gully management activities to stabilise gullies (change to gully activity parameters)

Each of the types of scenarios suggested above can be used to investigate delivery of sediment to the stream network and accumulation through the network. However until the other component models are developed this has limitations. For instance both the reservoir deposition and floodplain deposition component models are required for the routing through the network to be useful at any location where these features exist. Additionally for total loads to be estimated and other types of scenarios other sources such as bank and point sources need to be modelled.

Lastly until all component models that interact with suspended sediment are in place it is not possible to calibrate the model against water quality monitoring data from stream gauges. This limits the conclusions that can be drawn.

3.3.1 Setting up a dSedNet Scenario in Source

The steps to set up a Source scenario to use dSedNet models

1. Load the dSedNet plugin
2. Define a Source Catchment scenario using the *Geographic Wizard*
3. Define FU areas with the use of a landuse map (raster) which covers 100% of the catchment (a prerequisite for using the Spatial Parameteriser)
4. Select a Rainfall runoff model and assign parameters; and calibrate it
5. Define constituents (e.g. *Fine* and *Coarse*)
6. Select Constituent Generation (*Hillslope Model – dSedNet* and *Gully Model - dSedNet*) models and assign generic parameters

7. Assign spatial parameters to selected constituent generation models using the spatial parameterisation tool (described in next section)
8. Execute the temporal parameterisers for associated constituent generation models (described in next section).
9. The Source model is now ready to run, Click *Run*

Note: The parameterisation steps are pre-processing steps to running the model. The statistics generated from the temporal parameteriser are generated from the Source model outputs.

3.4 Spatial parameterisation

Spatial parameterisation has been developed as 'Core' capability. Its function is to allocate spatial values to model parameters that have spatial context within the model. For this to be achieved and be robust the FU⁵ areas must be assigned using a landuse layer that defines 100% of the FU areas across all catchments. The average value of the parameter layer that intersects the land use layer for a particular catchment is assigned to the model parameter.

Figure 5 and Figure 6 demonstrate the functionality of the spatial parameteriser using a simple example. Table 5 tabulates the results of the operation described in those figures.

⁵ For those not familiar with Source and its spatial characterisation of a catchment, the reader is referred to Welsh et al. (2012). FUs are functional areas and are the basic mapping unit within which land use etc are described.

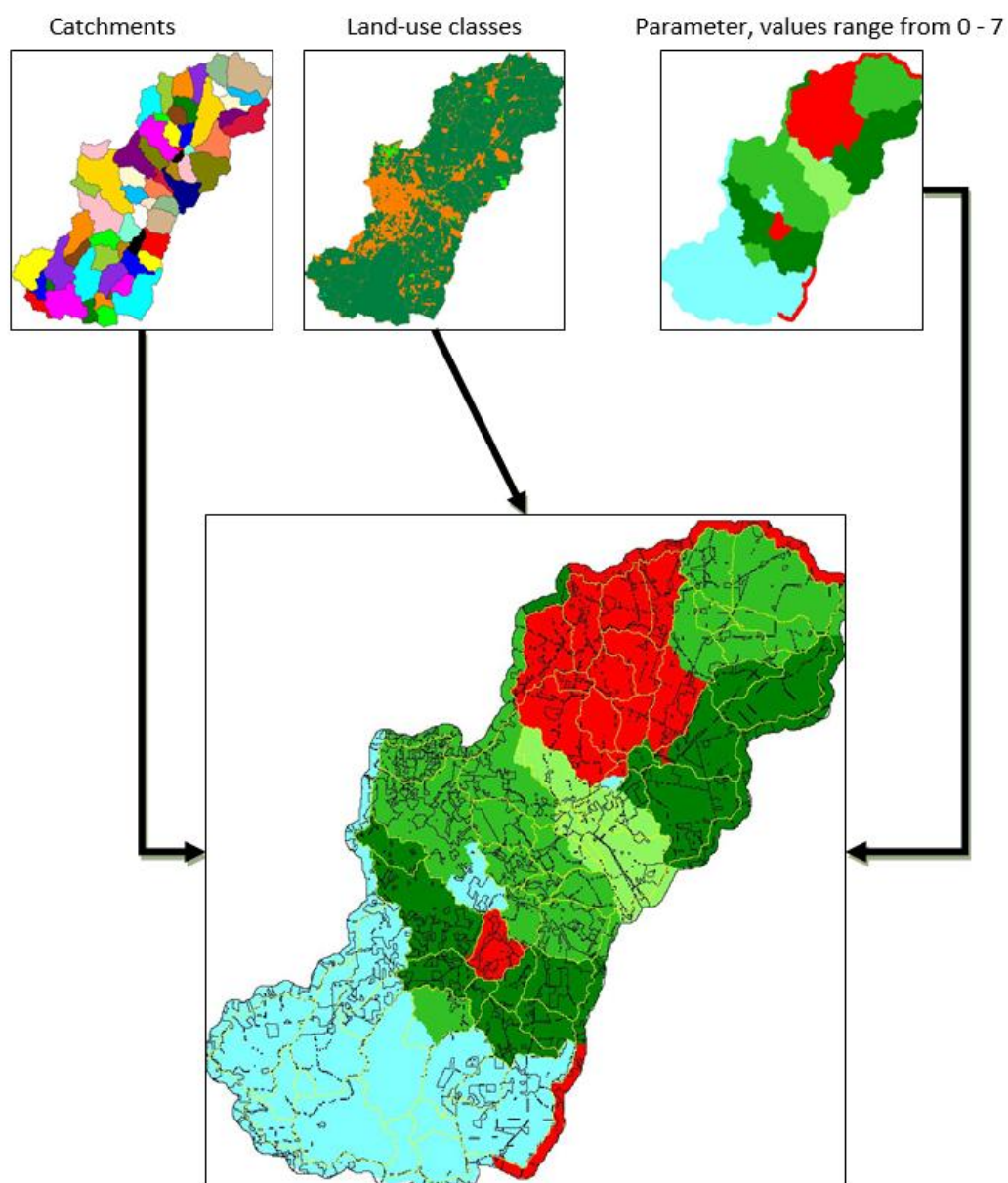


Figure 5, Map representation of the functionality provided by the spatial parameteriser

Table 5, The result from parameterising a model that exists only for landuses B and C

Catchment	FU/s in catchment	Model present in FU	Parameter avg. value
1	A, B	B	0.9
2	A, B, C	B, C	1.2
3	B, C, D	B, C	2.5
4	B, C, D	B, C	2.9
5	C, D	C	3.7

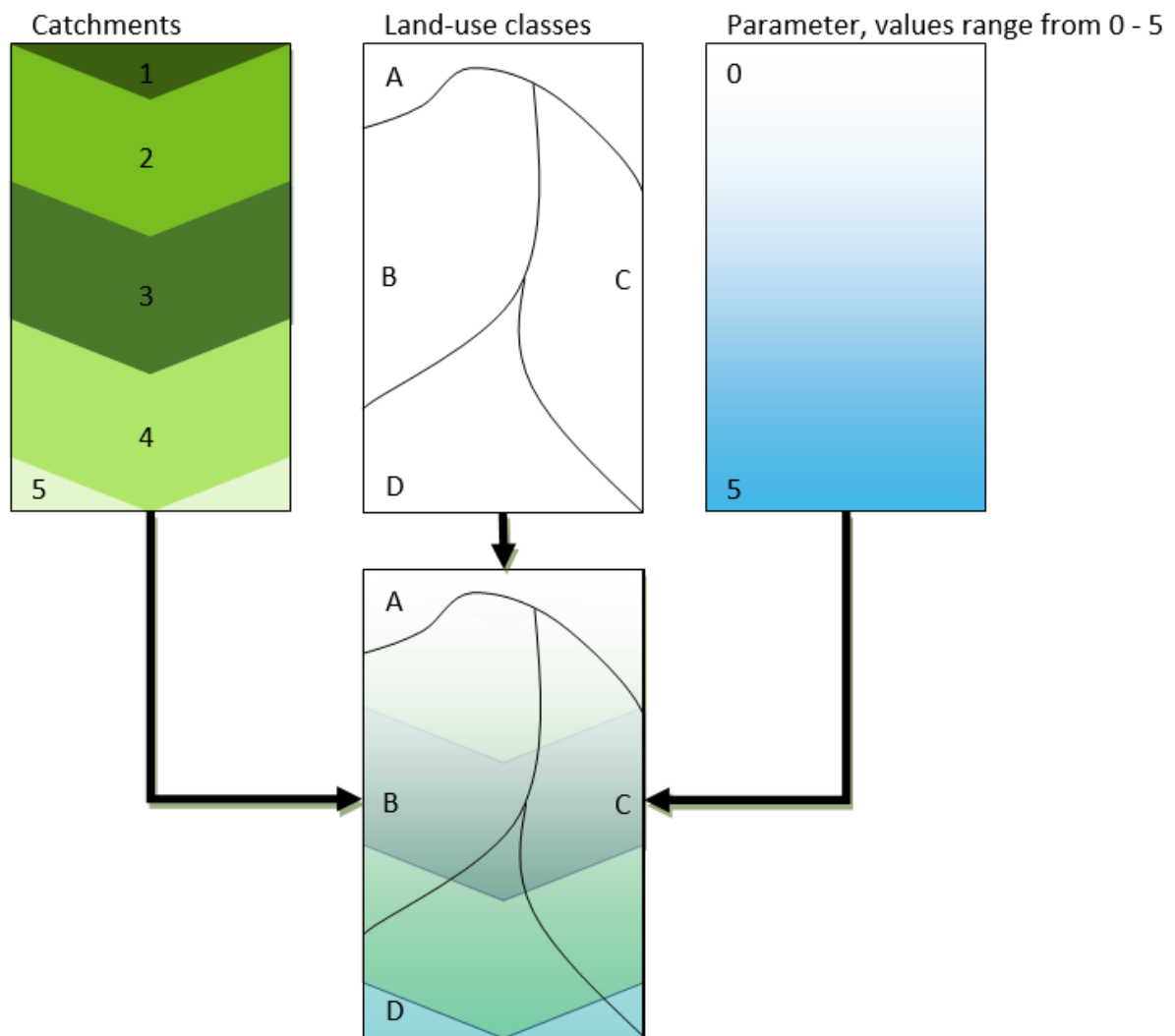


Figure 6, Schematic of the functionality provided by the spatial parameteriser

3.4.1 Using the spatial parameteriser

After configuring a scenario to use the dSedNet model and selecting *Edit* → *Spatial Parameteriser...*, the dialog (Figure 7) is shown.

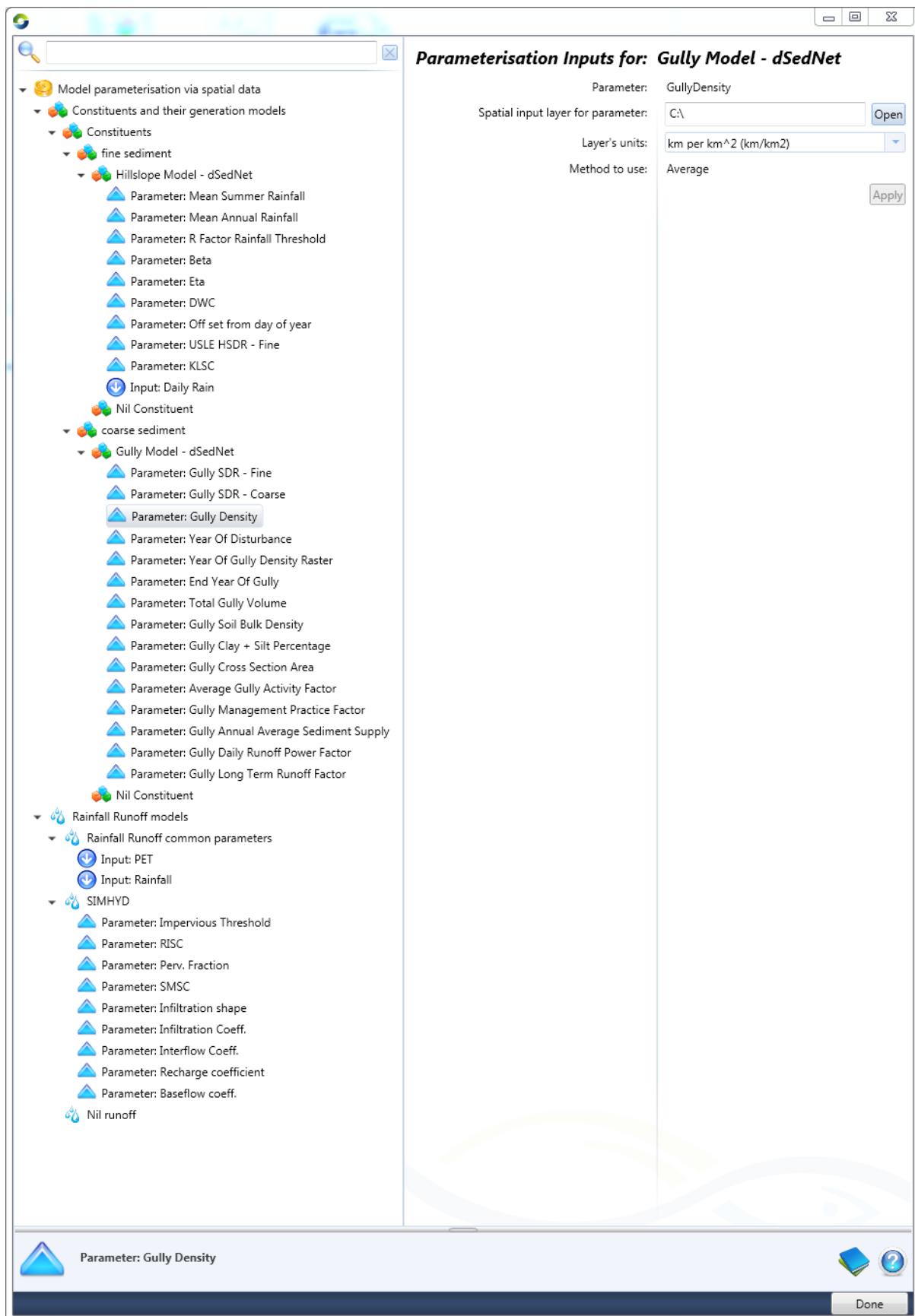


Figure 7, Spatial parameteriser dialog, using the gully erosion model as the example

The leaf nodes that make up the tree view on the left of the dialog are a list of model parameters. The associated models are ones that have been applied to the FUs. Each type of constituent generation model will appear per constituent (for example, in Figure 7, for the Constituent *fine sediment*, the assignment model is *Hillslope Model*) and each type of rainfall runoff model will appear.

Selecting a parameter from one of these lists populates the right hand side of the dialog with the name of the selected parameter, a text box and button for loading (*Opening*) a spatial layer, a drop-down list of measurement units to associate with the selected parameter, a method which will be used to aggregated the distribution of values and an *Apply* button. In the Figure 7 example, the selected parameter is *Gully Density*.

Spatial input layer for parameter: When a layer (raster only for this version) is loaded, it is validated against existing layers to ensure that it can be used correctly. The layer must be comparable with the previously loaded landuse layer – cell size (height and width), coordinates for the upper left and lower right and the number of rows and columns must match. Each cell in the loaded layer must have a non-null value for every non-null value in the landuse layer. If these constraints are not met, the layer will not be available for use – it will be deemed not comparable, and the text box will be highlighted in red (mouse over the box for a hint).

Layer's units: The layer's metadata is checked for a defined *Unit*. If this is not present, a warning is given (Text box is highlighted in yellow) and must be selected from the *Layer's Units* drop-down list. This drop-down list is derived from the unit specified within the model with units of the same dimension. For example if the model parameter unit is *millimetres, mm* the drop-down list will contain all units with the dimension equal to length, such as *metres* (the base SI unit), *kilometres*, or even *foot* (Imperial/US). This allows for unit conversion where the assigned unit is different to the one of the model. The input layer data are converted to match the model unit prior to applying to the model. Should your data units not appear on the drop-down list, automatic conversion cannot be performed – the data will need to be converted using another tool.

Methods to use: The only method that has been implemented is *averaging*. Future development would include other statistics such as minimum, maximum and total.

Apply: Once the layer is loaded and units defined, the *Apply* button can be selected. The average value of the parameter layer that intersects that of the landuse layer for a particular catchment will be assigned to the model parameter.

The result of this action can be seen in the dialog where the models were assigned, *Edit → Constituent Models...* and select the model of interest (e.g. *coarse sediment* in Figure 8). The parameters for that model are listed on the right side of the dialog. You can scroll across to see the complete list and the values assigned to the parameters.

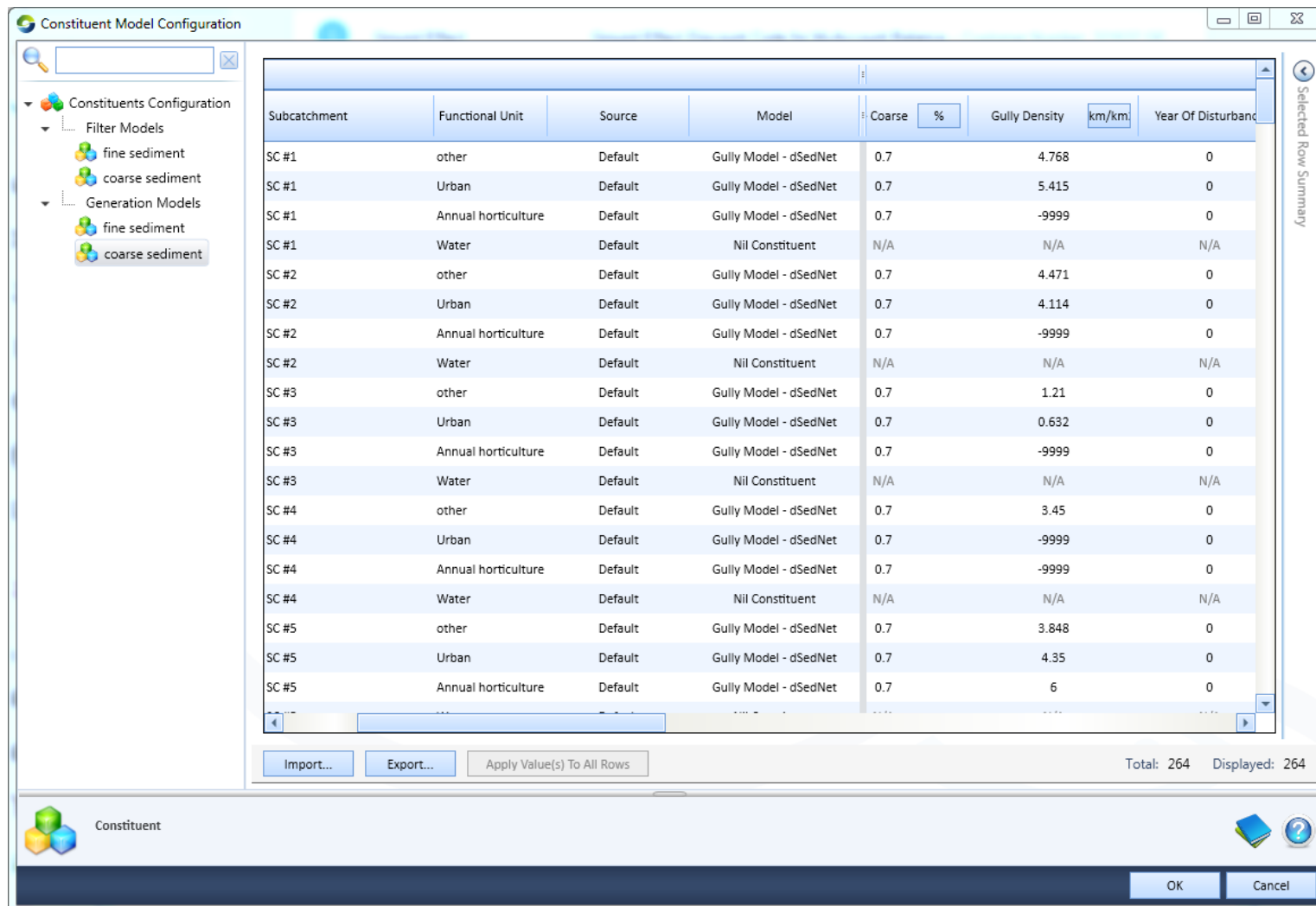


Figure 8, Constituent model configuration

Note that the units in this table may be different to those that you selected previously. This is just the predefined displayed units. You can select the preferred units by clicking the units and selecting from the list. The displayed units will change to reflect this change in units.

3.5 Temporal parameterisation

Temporal parameterisation has been developed within the dSedNet plugin. Its function is to parameterise model parameters with values obtained via analysis of a model's output time-series prior to simulation. For example the long term annual average of runoff from a FU can be used as a parameter value for a model (e.g. Gully model) allocated to that particular FU.

3.5.1 Using the temporal parameteriser

The temporal parameterisation for particular models in the dSedNet plugin has been implemented as a black box. The user only needs to set initial model parameter values and then run the parameteriser. The tool has been configured to record the required time-series while the model executes one full run (Note that changing the time period of the model run will produce different values. This may be a problem if the model is later executed over a different time period, e.g Drought vs Normal season). Finally the desired statistic is calculated and the result applied to the relevant model parameter for each FU with that model. This process is executed as a pre-process step before the actual model run.

Table 6, Gully erosion model parameters that require a value before executing the temporal parameteriser

Component module	Parameter
Gully	Gully density
	Gully cross-sectional area
	Gully year of disturbance
	Gully year density raster
	Gully soil bulk density
	Gully daily runoff power factor

Table 7, Hillslope and gully erosion model parameters that are assigned by the temporal parameteriser

Component module	Parameter
Hillslope	Mean summer rainfall
	Mean annual rainfall
Gully	Total gully volume
	Gully annual average sediment supply
	Gully long-term runoff factor

4 Trial of dSedNet plugin in the Onkaparinga catchment

This section describes the testing of the plugin, using the latest Source model for the Onkaparinga developed by SA EPA and SARDI. A short description of the study area is included - for a more detailed description of the study area the readers are referred to the companion report (Kuhnert et al. 2015) and Fleming et al. (2012). The Source model is described in Fleming et al. (2012) and Thomas et al. (2010).

4.1 Trial strategy

The purpose of trialling was to test the robustness of the code and its use within Source, using data that was familiar to the project team. Due to the models being uncalibrated, the trial was restricted to the baseline parameterisation and look for patterns in the results, matching expected behaviour and/or behaviour previously reported (e.g. Wilkinson et al. 2005). This seemed more sensible than running scenarios (e.g. changes in landuse) which would be difficult to interpret. This approach would also allow for comment on the performance of dSedNet over earlier studies.

Wilkinson et al. (2005) used SedNet to simulate average annual sediment budgets (generation, transport and deposition) across the catchments of the MLR. No effort was made to compare those simulated loads to observed loads, most likely due to a dearth of sediment process data in the region. As our study has developed components of the same model (albeit at a daily time-step), the first point of commentary is testing against results from previous use of the same model in the same area. The Onkaparinga catchment was selected for this as a significant component of the MLR, using data from Houlgrave weir (A5030504). To the extent that was possible, the same input data were used as per the Wilkinson et al. (2005) report. However a number of critical differences remain: hydrology is a key point of departure, where the SedNet application of Wilkinson et al. (2005) used regional relationships as described in the SedNet manual (Wilkinson et al. 2004); our study has used the SIMHYD rainfall-runoff model as calibrated in Kuhnert et al. (2015). The data are described in a little more detail later in this section.

The implementation of stream bank erosion and instream processing was not possible in this project, so the commentary is confined to the hillslope and gully erosion module outputs.

Two other commentaries are made. While a comprehensive water quality data set is available in the MLR for TSS, specific measurements of sediment generation, transport and deposition are not available. For this reason, TSS measurements are used as the point of comparison with sediment load simulations from dSedNet. While the fine and coarse sediment loads estimated by dSedNet are not directly comparable to TSS concentrations,

patterns and trends of loads over time were considered to be relevant. Commentaries are thus made against:

- TSS results from using Source with the EMC/DWC approach (Fleming et al. 2010)
- Statistically-derived TSS results reported in Kuhnert et al. (2015).

As well as testing temporal patterns of load simulation, this exercise tested the stability and robustness of the software which comprises the dSedNet plugin.

4.2 Study area

The catchments of the Mount Lofty Ranges (MLR) (Figure 9) are a crucial water resource that is important to the well-being of the people of Adelaide. There are seven reservoirs on rivers and streams of the MLR to harvest the relatively high rainfall and supply Adelaide with drinking water. This drinking water is supplemented with water diverted from the River Murray. Water collected within the catchments is a significant component of the total supply needs of Adelaide and is the most cost effective water source.

The MLR are used for different purposes including harvesting of drinking water, agriculture, intensive horticulture, recreation, rural living, tourism, environmental conservation and urban environments. These multiple uses place pressure on the water resource and can impact on water quality.

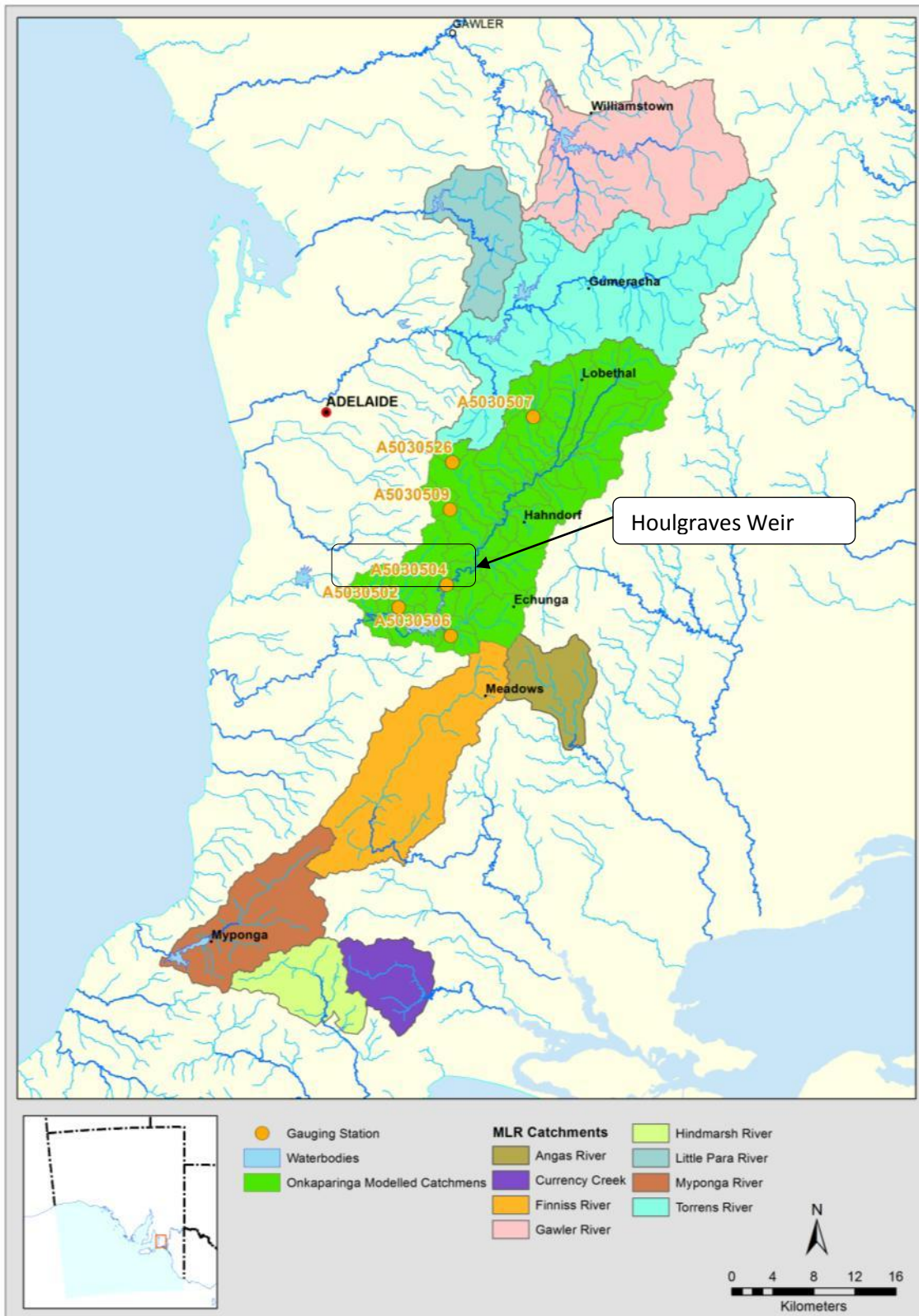


Figure 9, Map showing the location of modelled Onkaparinga catchment

4.3 Source Catchments implementation

Source Catchments and its precursors have been applied as tools (in the MLR catchment) for several years. The Source conceptualisation of the MLR catchments is provided in Figure 10 which shows the Onkaparinga catchment, sub-catchments, hydrological network, and gauging stations used for hydrological parameters.

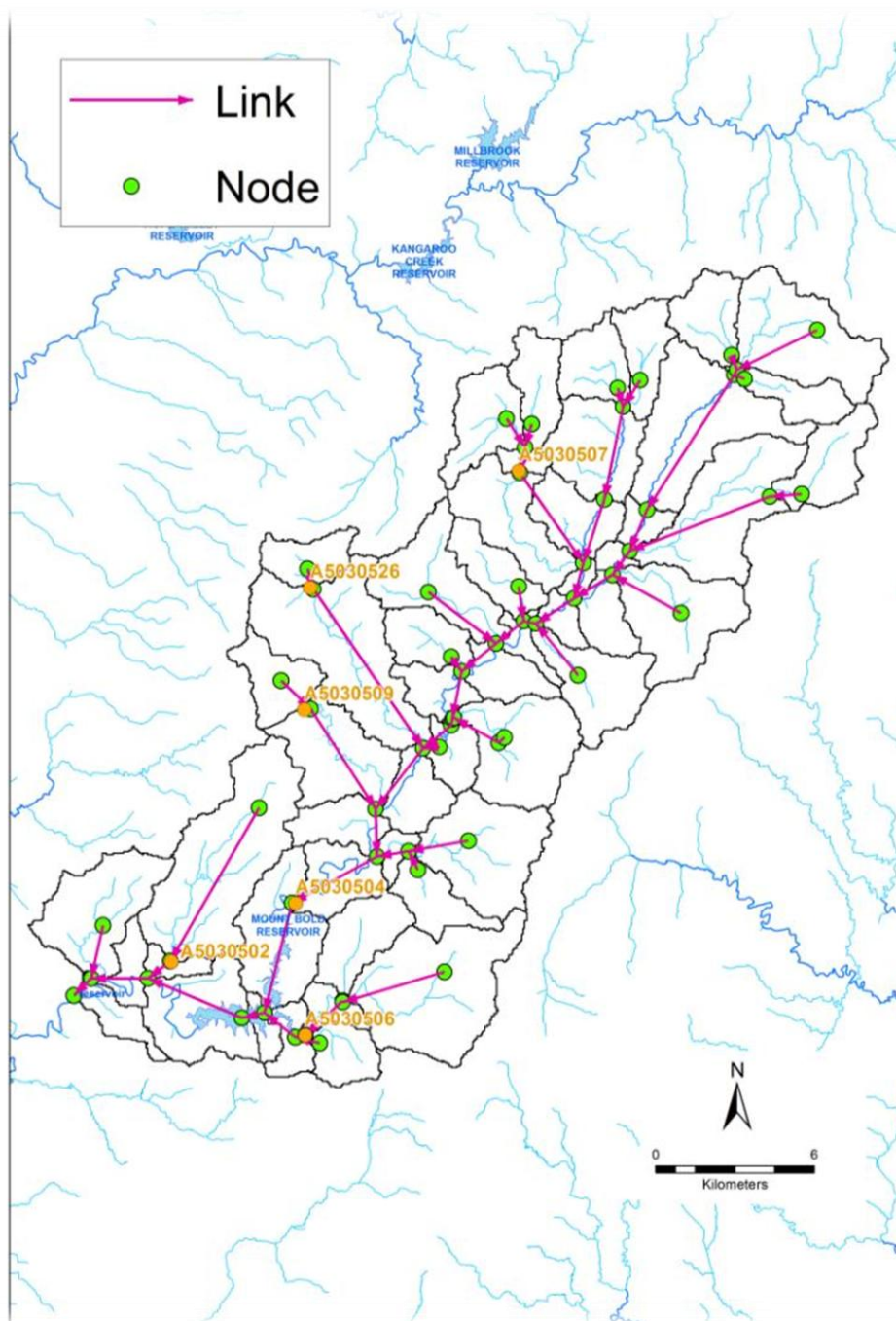


Figure 10, Node-link diagram of the Source model conceptualisation of the modelled Onkaparinga catchments

Rainfall and streamflow for Houlgraves Weir are shown in Figure 11. Rainfall is measured at the weir. While the simulation period was from 1980 to 2013, a shorter time period is displayed below to retain clarity. There is considerable year-to-year variation in the amounts of rainfall and runoff.

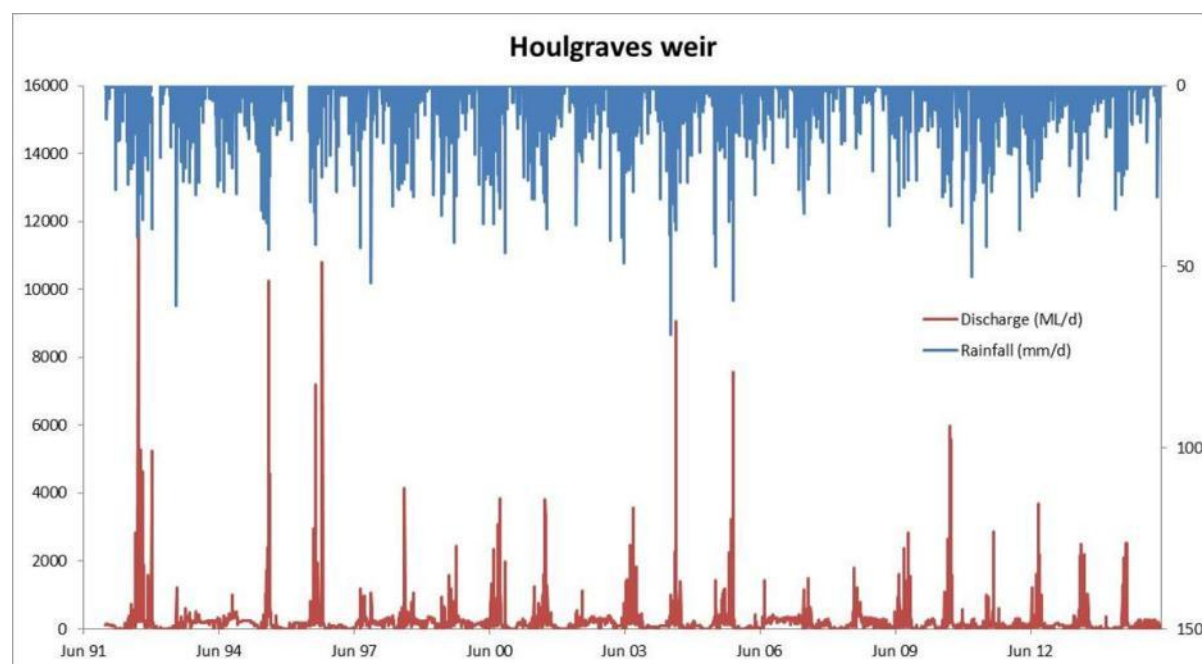


Figure 11, Observed rainfall and streamflow for the Onkaparinga River at Houlgraves Weir (A5030504) for the period 1991 to 2013

Landuse categories used in the Source model are given in Table 8. The first column shows landuse categories in the existing Source model of the MLR (Thomas et al. 2010), while the second column shows the combined categories used for hydrological calibration of the Onkaparinga model (Kuhnert et al. 2015).

Table 8, Landuses in the catchment area contributing to Houlgraves Weir

Landuse Functional Units (FU)	Broad categorisation	FU area (ha)	% FU
Broad-scale annual horticulture	non-urban	1721.42	5.38%
Broad-scale perennial horticulture	non-urban	361.17	1.13%
Conservation area	non-urban	4074.14	12.74%
Dense urban	urban	4223.41	13.21%
Farm dams	water	1770.30	5.54%
Grazing	non-urban	319.72	1.00%
Intensive grazing	non-urban	12174.07	38.08%
Intensive production	non-urban	1211.86	3.79%
Recreation and culture	non-urban	39.80	0.12%

Landuse Functional Units (FU)	Broad categorisation	FU area (ha)	% FU
Rural living	urban	180.96	0.57%
Utilities	urban	510.17	1.60%

In total, the contributing area contained 76% non-urban, 17% urban and 7% water land uses.

4.4 dSedNet parameterisation

To enable the trial, the dSedNet model was parameterised to match as closely as possible with those reported in Wilkinson et al. (2014) (Table 9).

Table 9, Description of input data and values used in Wilkinson et al. (2014) and this trial. ‘Equation’ (column 3) identifies the equation in Wilkinson et al. (2014)

Parameter	Description	Equation	Value	Basis
HSDR	hill sediment delivery ratio	1	Spatially variable	5% is an appropriate value for hillslope delivery in southern Australia (Prosser et al. 2001).
R	rainfall erosivity factor	2	Spatially & temporally variable	R was derived from the National Land and Water Resources Audit (NLWRA; Lu et al. 2001, 2003a)
K	soil erodability factor	2	Spatially variable	K was derived from the National Land and Water Resources Audit (NLWRA; Lu et al. 2001, 2003)
L, S	slope length, gradient	2	Spatially variable	L and S factors were calculated using a 10m DEM as described by Lu et al. (2003)
C	cover factor	2	Spatially & temporally variable	The NLWRA satellite greenness data set with a high-resolution vector landuse dataset was converted to a raster with 20m cells.
P	practice factor	2	1	The effects of practice were incorporated within C where known
Pf	proportion fine	3, 5	0.3 fine	Default assumed value
Ps	soil bulk density	3	1500 kg/m ³	approximation
aG	gully cross section	3	10	Observed average gully depth is 1 m. Average gully width of 10 m was measured from aerial photographs, was used to set the gully cross sectional area to 10 m ² .
LG	gully length	3	S	Spatial pattern of gullies was derived from Hughes et al. (2001) and the Riparian Zone Mapping Project in 1996 (DWLBC, 1997).
T	gully age	3	100	
fG	runoff factor	3	1	Assumed to be

Parameter	Description	Equation	Value	Basis
Mg*	Management factor	3	S	The rate of suspended sediment yield from gullies was reduced from the average rate by 50%, based on measurements in the Murrumbidgee River catchment (G. Caitcheon, unpublished data).

* This factor is not yet implemented

4.5 Baseline

The results presented here from dSedNet are for the hillslope and gully erosion models only, using the 25m KLSC layer. There was no addition or attrition in the riverbank or floodplain – all sediment reaching the stream was assumed to go directly to the measurement point, which was Houlgraves Weir.

Two sets of dSedNet results are presented, from two rainfall-runoff model (SIMHYD) calibrations. The multi-region simulation used separate SIMHYD parameters for each region defined by a downstream gauge. The single-region calibration treated all sub-catchments above Houlgraves Weir as a single region, i.e. they all had the same SIMHYD parameters. These two approaches were used to better match simulated with observed flow.

The change from multi-region hydrology to single-region hydrology generally increased peak flows in large events to closer match with observed values. A key event where simulated flows diverged from observed flows was in August 2004. This is shown in Figure 12, and reveals how small changes in calibration methodology can affect simulated flow in major events such as this, which transport large amounts of sediment. This demonstrates the sensitivity of sediment transport to peak flow rates.

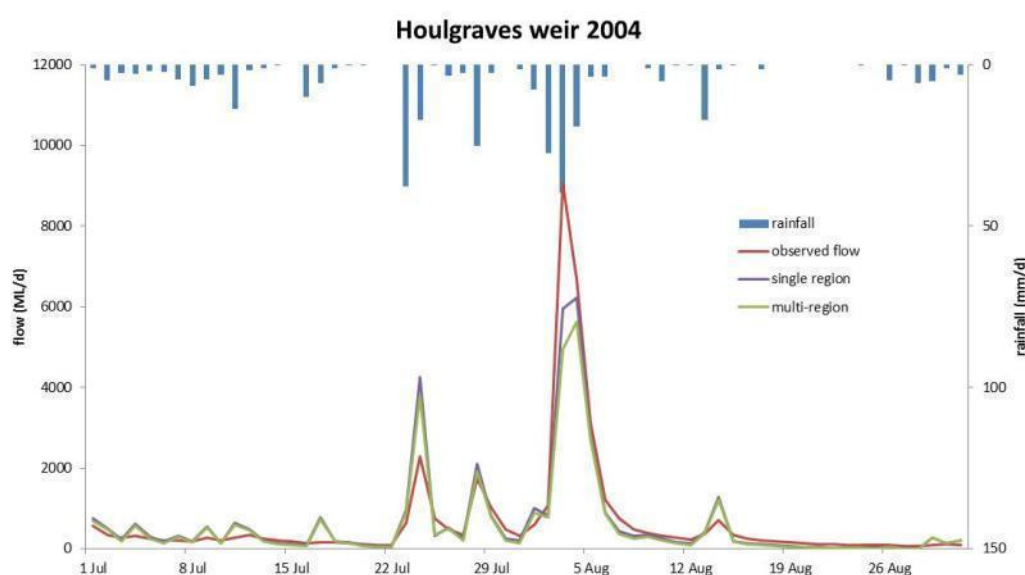


Figure 12, Rainfall, observed and simulated flow at Houlgraves Weir in August 2004

Hydrological modelling is not the focus of this report, so it is not analysed in depth here. However, the main increase in sediment yield from dSedNet came from coarse sediment after changing the hydrology to a single region. This indicates the importance of getting the hydrology ‘right’. SIMHYD parameters used in the model are given in Appendix B . It is also important to understand the observed data. As shown in Figure 13, there is a general increase in TSS with daily flow rate. Unfortunately, this is driven by a single sample (the 2004 flow event) at 465 mg/L, and so could not be used as a predictive relationship.

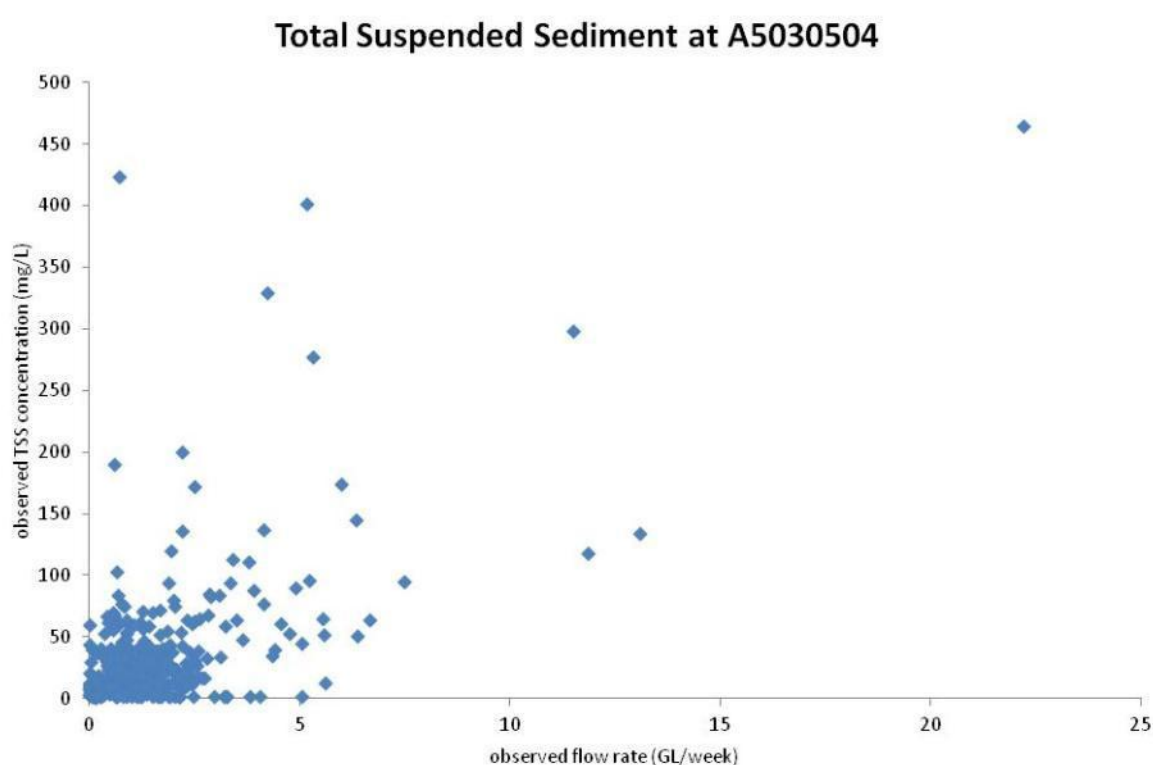


Figure 13, Plot of observed flow vs observed TSS concentration at Houlgraves Weir (A5030504)

The predicted mean annual load from the multi-region calibration was 15.8 kTonnes, while the predicted mean annual load from the single-region calibration was 19.4 kTonnes (Table 10). The yearly loads are plotted in Figure 15.

Table 10, dSedNet predicted mean annual load (kTonnes) to Houlgraves Weir over the period 1/1/1980 to 3/12/2013 (34 years), for both the multi- and single-region hydrological calibrations

Component	dSedNet multi-region kT/yr	dSedNet single-region kT/yr
Suspended (fine) sediment from hillslopes	3.1	3.1
Suspended (fine) sediment from gullies	2.7	2.4
Bedload (coarse) sediment from gullies	10.0	13.8
TOTAL	15.8	19.4

Figure 14 shows the relationships between simulated flow and concentrations of coarse and fine sediments, respectively. Compared to observed flow and concentration (see Figure 13), simulated concentrations are much higher. This is possibly a consequence of using the Wilkinson et al. (2005) DWC value of 100 mg/L for TSS rather than 25 mg/L as per local data.

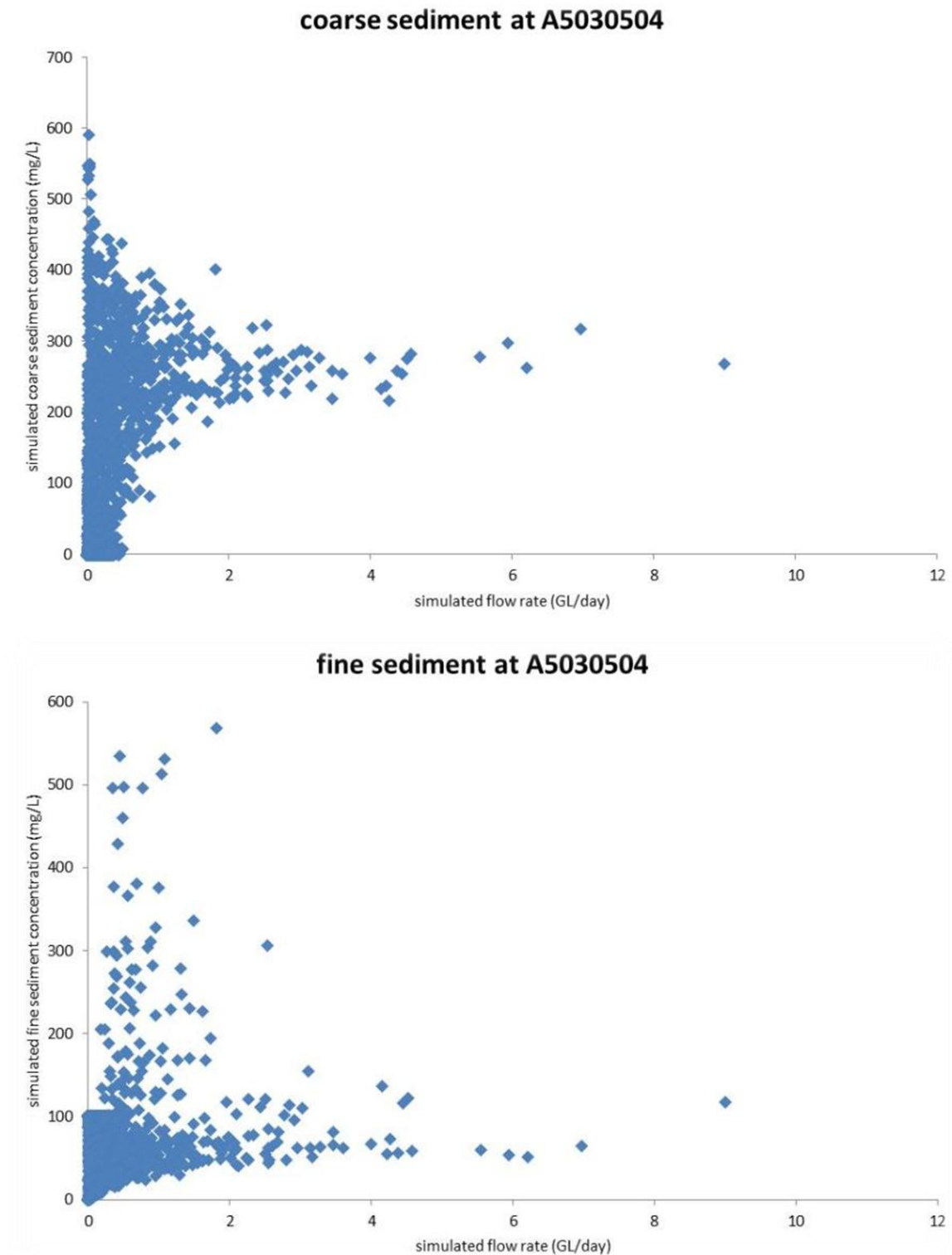


Figure 14, Simulated (top) coarse and (bottom) fine sediment concentration (mg/L) vs simulated flow rate (GL/day) at Houlgraves Weir (A5030504)

4.6 Trial results

4.6.1 Against SedNet sediment budgets (Wilkinson et al. 2005)

The loads produced by dSedNet are comparable to the first three components of the Wilkinson et al. (2005) sediment budgets (Table 11).

Table 11, SedNet annual sediment budgets from Table 4, Wilkinson et al. (2005)(Load kT/yr) and dSedNet multi-and single-region runs

Component	Load kT/yr	dSedNet multi-region	dSedNet single-region
Suspended (fine) sediment from hillslopes	2.9		
Suspended (fine) sediment from gullies	4.0		
Bedload (coarse) sediment from gullies	8.1		
Total of above 3 components	15.0	15.8	19.4
Suspended (fine) sediment from riverbanks	2.9		
Bedload (coarse) sediment from riverbanks	2.9		
TOTAL	20.8		

Given the differences in hydrology and model structural changes between this project and that of 2005, and the lack of extensive calibration of either approach, there is remarkably good agreement in the predicted mean annual load (15.8 and 19.4 vs 15.0). Overall yearly sediment loads and trends were close to those of Wilkinson et al. (2005). No attempt was made to optimise parameters for load estimation, for the following reasons:

- these are partial sediment budgets, and are not comparable to observed TSS values at Houlgraves Weir
- there are insufficient data on sediment generation, transport and deposition in the study area
- extensive parameter estimation was outside the scope of the project.

The good agreement between sediment loads estimated by dSedNet and prior estimates by Wilkinson et al (2005) showed that the current iteration of the model produced similar overall results. However, dSedNet has a number of advantages over SedNet. These include the ability to investigate within-year changes (e.g. ground cover, rainfall patterns, management impacts) and the ability to be run by any Source user.

4.6.2 Simulated loads against EMC/DWC loads (Fleming et al. 2010)

This analysis looked at sediment loads generated by dSedNet (fine and coarse) and TSS generated by the same runoff model using EMC values, and is shown in Figure 15. No

comparison is intended between absolute values, as this is not a calibrated model. The main point of interest is the patterns of change in load over time. For this reason, and because simulated coarse sediment loads are much higher than fine sediment or TSS, the coarse sediment has been plotted on a second y axis.

The simulated loads of fine sediment diverged somewhat from those of TSS which were simulated using the EMC/DWC approach. This was expected, due to the different constituent generation models. Changes in coarse sediment loads, however, followed simulated TSS very closely. This was unexpected, even though the absolute amounts were different. An identified shortcoming with the EMC/DWC approach is its inability to match the year-to-year variation seen in observed loads. This is due to the fact that it is developed by an averaging process. The finding that simulated coarse sediment loads followed simulated TSS loads so closely implies that no improvement can be made by the dSedNet approach. On closer investigation, however, this was related to the parameter settings within dSedNet. The settings used by Wilkinson et al. (2005) for coarse sediment mimicked the behaviour of TSS, as would seem logical. The dSedNet model has many adjustable parameters which are not available in an EMC/DWC model. One of these (Gully Daily Runoff Power Factor) was changed from 1.0 to 5.0, and the simulation was re-run. The revised simulated loads are shown in Figure 15 (bottom plot). This ability to change the description of constituent generation behaviour is one of the many advantages that dSedNet has over the EMC/DWC approach.

The pattern of simulated coarse sediment loads shown in Figure 15 (bottom) is more extreme than those of either fine sediment or TSS, in the same way that observed TSS loads are more extreme than simulated ones. The parameter change was not a realistic one (in fact the units of coarse sediment have changed from kT to MT), but demonstrates the responsiveness of sediment load estimates to adjustable parameters. This is not possible in an EMC/DWC model.

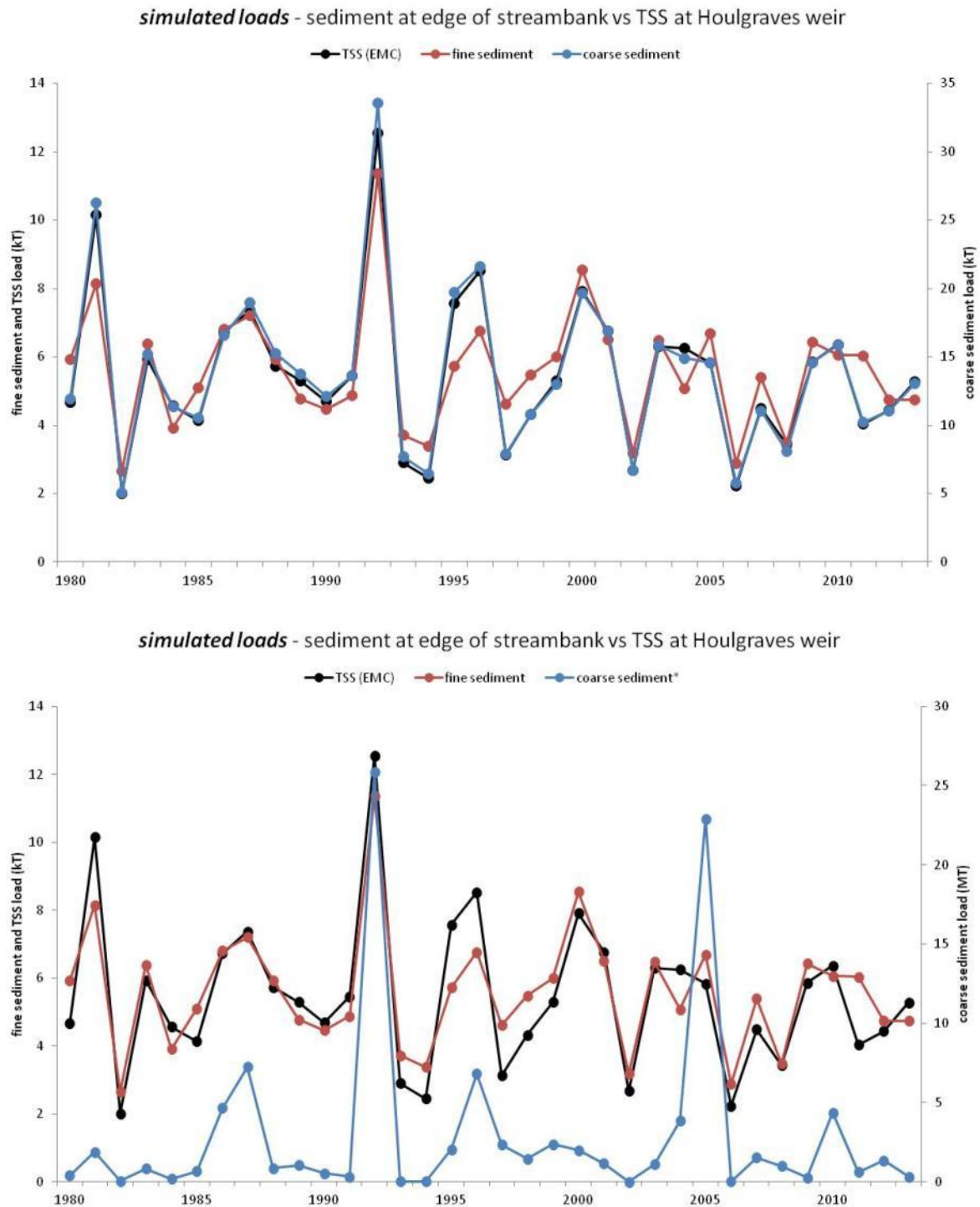


Figure 15, Annual simulated sediment loads from dSedNet and EMC/DWC approach at Houlgraves Weir for the period 1980 to 2013 with Gully Daily Runoff Power factor of (top) 1.0 and (bottom) 5.0

4.6.3 Against statistically derived loads (Kuhnert et al. 2015)

This project sought to provide alternative approaches to model sediments in the Onkaparinga River catchment. The approach of Kuhnert et al. (2015) used the Loads Regression Estimator (LRE) to evaluate a series of flow aggregation and land use variables on the prediction of sediment (and nutrient) concentrations. The statistical approach is strongly

data dependent, and while this facilitates the understanding of uncertainty, the difficulty in identifying parameters linked to land uses in the LRE statistical approach makes it less suited for testing the scenarios of changing land use. Essentially one must assume that these land use related parameters are stationary when using the LRE model to hindcast or forecast sediment loads. In comparison, the potential for spatial and temporal variation in model inputs available in dSedNet will facilitate the investigation of these dynamic characteristics.

In Figure 16 the LRE load estimates downstream of Houlgraves Weir are plotted against the dSedNet simulated loads contributed to the river network for the area upstream of this gauging station. The daily behaviour is examined to demonstrate the responsiveness of the two models to rainfall and runoff.

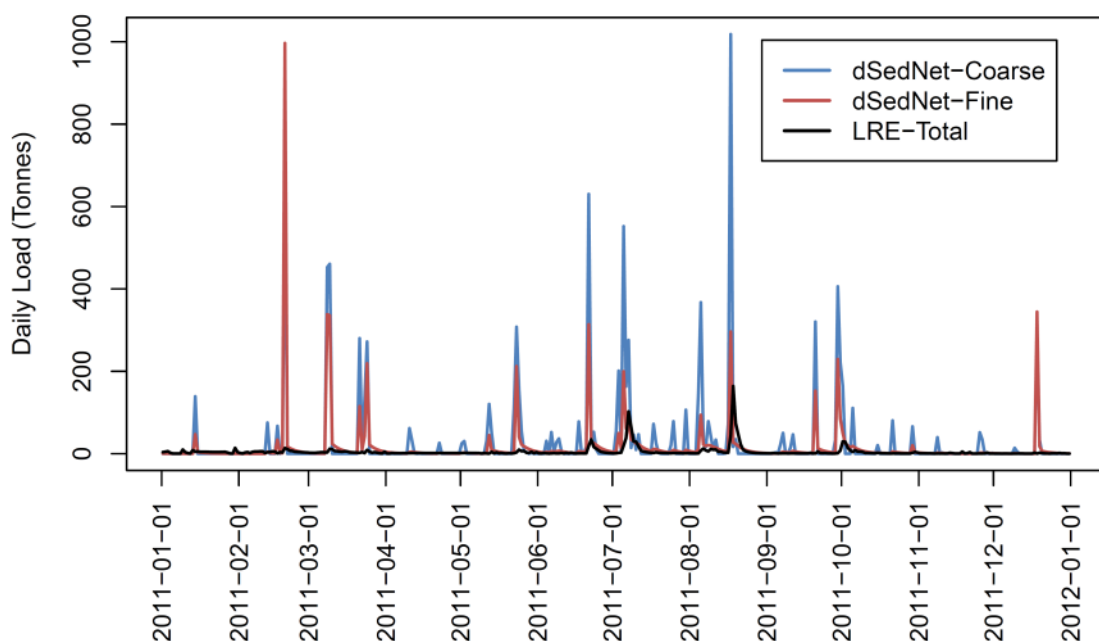


Figure 16, dSedNet (coarse and fine) simulated daily sediment loads and Loads Regression Estimator (LRE, Total) load estimates

The sediment mass contributed by hillslopes, as modelled by dSedNet, is determined by precipitation, rather than runoff, while annual gully sediment mass contributions are disaggregated to daily fluxes using a function that relies on daily flow (Wilkinson et al. 2014). This disaggregation function uses a power exponent to distribute sediment according to flow magnitude; it is generally recommended that the exponent of this equation be manually set for a given application; a default value has been used here (see equation 4 in Wilkinson et al. 2014). This is a very sensitive parameter which will require calibration when suitable data is available (see section 4.6.2). The difference in the responsiveness of the LRE model and the two modules implemented within dSedNet is obvious when compared as time series. The dSedNet load estimates are consistently 'spiky' throughout the year, while the increases in LRE estimates are concentrated in the winter, due to the effects of flow

discounting (Figure 15). Any detailed comparison are however superfluous as the dSedNet model requires more development and calibration.

4.6.4 Against observed

As the model has not been calibrated, comparison against observed has little meaning in terms of actual numbers, but can provide some insights into model performance. Observed TSS loads are generally much lower than the dSedNet output, except for 2004 (see later comments) (Figure 17). This result would be expected as the uncalibrated dSedNet is effectively predicting potential, not actual, load. Figure 17 shows simulated and observed loads from 1999 to 2008, which was the time period during which TSS data was available.

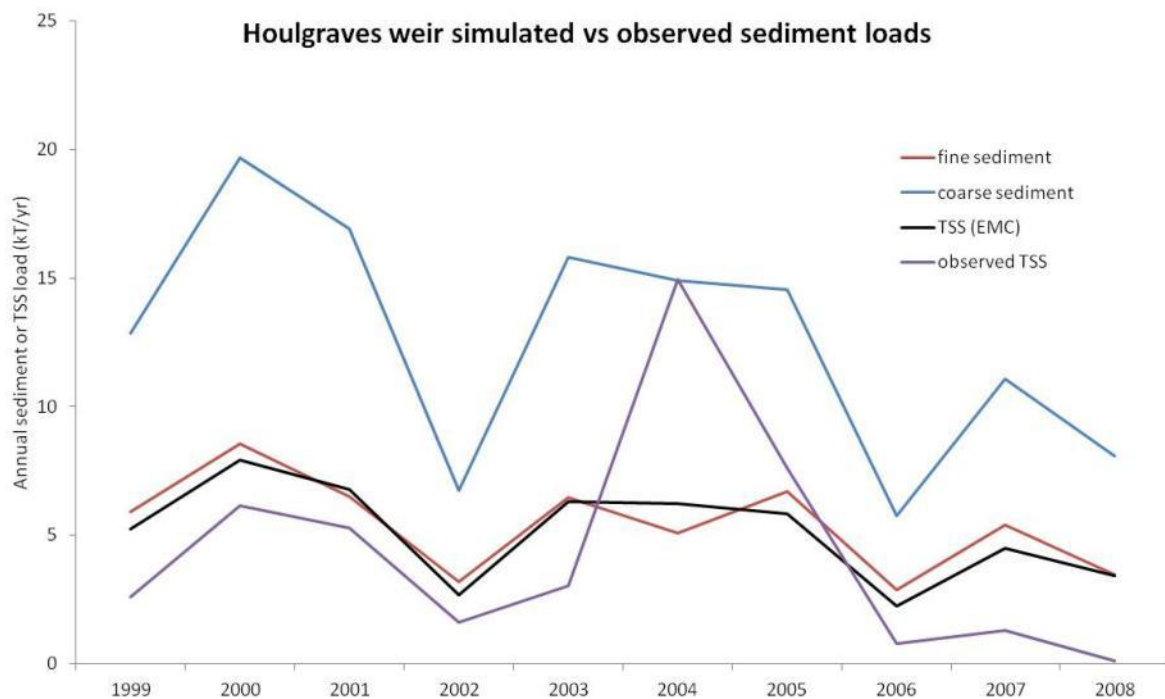


Figure 17, dSedNet simulated sediment loads and observed TSS data. Note that the plot also includes simulated load from the EMC/DWC approach (TSS(EMC))

All simulated loads tended to follow observed TSS loads, with the exception of 2004. The spike in the observed load in 2004 was investigated and is related to a very high flow event on 4 August which was not reproduced by SIMHYD. This was discussed earlier (Section 4.6.2 and Figure 12).

5 Benefits of the approach

The Goyder Institute for Water Research and its partners have invested in a research activity to improve the modelling of water quality within the MLR. The products of that investment are a partial implementation of the dSedNet plugin for Source and a set of small trials to test the software in the Onkaparinga catchment of the MLR. Even though the implementation is partial, this exercise has given us sufficient insights to describe some of the key benefits of the approach, and realisation of the investment made to date.

Why would we use dSedNet, when an EMC/DWC Source model has already been constructed and calibrated for the MLR catchments?

dSedNet simulates daily sediment movement through hydrological networks. Sediment is a primary agent of poor water quality. It is also a common thread between most constituents of concern in regard to water quality. Because of this, modules can be developed for constituents associated with sediment. This has been implemented in the Queensland Great Barrier Reef model. As well as fine and coarse sediment, this has included:

- Particulate Phosphorus
- Dissolved Organic Phosphorus
- Filterable Reactive Phosphorus (Dissolved Inorganic Phosphorus)
- Particulate Nitrogen
- Dissolved Organic Nitrogen
- Dissolved Inorganic Nitrogen, and
- Pesticides.

As a spatially distributed model, dSedNet keeps track of spatial input data so that outputs can be traced back to their source. This is invaluable for targeting remedial activities, and is not available in an EMC/DWC model where the spatial data are used only to calculate land areas within each sub-catchment. Spatial location of sources allows cost: benefit analyses of environmental interventions, as well as scenario modelling of on-ground works.

Why use dSedNet, when annual SedNet is available?

As described by Searle and Ellis (2009), developments in remote sensing and in the WaterCAST (Source) modelling platform create an opportunity to incorporate both temporally and spatially variable estimates of cover into catchment water quality modelling. They used a daily SedNet model in WaterCAST, and the Bare Ground Index (a satellite estimate of ground cover) to estimate sediment loads. Searle and Ellis (2009) found that both the calibrated EMC/DWC base model and the newly developed SedNet model gave sound temporal estimates of sediment load. However, the fixed EMC/DWC modelled sediment concentrations did not closely match observed concentrations, while the SedNet

Variable Cover model estimates did a better job of predicting concentrations. They found that the ability to incorporate spatially and temporally variable input data into WaterCast allowed them to more realistically determine sediment generation hot spots. It thus gave them a much better understanding of the management required in specific areas of the catchment.

A major advantage of dSedNet is the ability to anticipate specific events (e.g. impacts of large flow) at different times within a year, and the ability to vary inputs during the year. For example if, say, climate change affects the frequency of summer storms, how does this affect water quality if there is heavy runoff when there is low ground cover? Does it really matter if graziers run out of feed in autumn and let stock into their fenced riparian areas?

<i>Why use dSedNet in the MLR?</i>

A spatially distributed model such as dSedNet gives the opportunity to target remediation at specific locations within a catchment. Before and after modelling can be carried out to determine the cost: benefit of on-ground works before or after they have been implemented. An excellent water quality data set is available for setting up dSedNet, although this was collected for EMC/DWC-type modelling approaches, and there is no data on sediment transport and deposition processes.

6 Next steps

6.1 Ongoing use in Mt Lofty catchment

The MLR provide a unique opportunity to further test and progress the dSedNet approach. This is primarily due to the richness of the excellent water flow and quality data set. This data extends back to the 1970s, and is probably unparalleled in Australian catchments which have Source models.

The dSedNet model consists of a number of erosion, transport, and deposition modules as shown in Figure 4. Due to resource constraints, work was limited to developing the spatial parameteriser tool (in Source core), the temporal parameteriser tool (plugin), and the Hillslope erosion and Gully supply models (plugins). Hillslope and gully models were prioritised as they were considered to be the dominant processes for sediment generation in the MLR. This assumption needs to be tested. If that is the case, then the stream-bank supply model may not be needed in the MLR. There are few floodplains in the MLR, so the floodplain deposition model may not be required. The quality of water entering the reservoirs is of prime importance (not the water overflowing them), so the reservoir deposition model may not be needed.

6.1.1 Calibration of the hillslope and gully models

The above discussion of hillslope and gully processes suggests that calibration of the Hillslope and Gully models may be the next step. Several assumptions have been made in arriving at this conclusion – these could be tested relatively easily in a desktop study. It may be that development of dSedNet in the MLR could be fast-tracked if these assumptions were true.

6.1.2 Using existing particle size data to establish sediment fraction (fine vs coarse)

A limitation of the existing data set is that the only sediment parameter which has been measured is TSS - not the particle size ranges of sediment. However, some particle size data are available for samples which have also been analysed for TSS. An assessment of the relationships between TSS and particle size across all available data may greatly assist further development of dSedNet in the MLR. Can TSS values be used as a surrogate for sediment fractions? This could also be investigated by a desktop study.

6.1.3 Using local sediment deposition data

There is no comprehensive information available in the MLR on sediment generation, transport and deposition. There may be indirect sources, however. For example, SA Water

installed a sedimentation basin in the Cox Creek catchment in 2006. This has been emptied of sediment several times. Estimates of sediment yield could be compared to TSS concentrations of water entering and leaving the basin – both the entry and the exit have a water quality sampling station. Investigation of local data sources, as well as potentially transferable data from outside South Australia, may eliminate the need for costly field studies.

6.1.4 Running scenarios

The gully and hillslope models do allow for some limited scenario analysis (refer to Section 0). Setting up and running scenarios should be undertaken as part of trialling of the product. Comparing scenario results to baseline (effectively comparing like to like in terms of model implementation) would assist with exploration of the sensitivity of the models to changes in input parameters.

6.2 Ongoing development of the dSedNet plugin

6.2.1 Peer review of the gully and hillslope model code

While the trial described in this report has been a reasonably robust test of the quality of the parameterisers and the dSedNet plugin coding (i.e. behaviour as expected, no untapped errors or error conditions), we would recommend that peer review of the code be undertaken, due to the rapid nature of its development. The implementation was undertaken by a seasoned software developer, with many years' experience working with Source, plugins, and catchment models – however the specifications were largely extracted from the Qld government code, which had evolved over time and contained many extraneous routines that required deciphering. Peer review may also uncover streamlining in the implementation, which could improve and reduce the development of the outstanding component models.

6.2.2 Completing the dSedNet plugin

The development of the spatial parameteriser was a significant task which then precluded development of more than the hillslope and gully models. We view this as a worthwhile and necessary investment as it significantly reduces the time taken to setup up the dSedNet models (in fact any model that has spatial parameters).

In a SedNET workshop hosted by CSIRO in late 2013, a high level plan was prepared covering the key components required to complete development and deployment – the streambank generation model, the deposition models (reservoirs, farm dams, instream), and extending these from sediment to nutrients (total phosphorus and total nitrogen). Additional user interface and reporting functionality, and documentation, would be included in a fully tasked workplan.

CSIRO, in particular its Land and Water Unit, has an interest in continuing with the implementation of dSedNet, and is actively looking for opportunities to fund its development and build the dSedNet community.

6.3 Reflections

This research activity saw the development of a coherent multi-agency team (CSIRO, SA EPA, SA Water, SARDI) that worked hard and well to deliver a product that sufficiently realised the investment within the budget scope. The decision to include a case study (as a trial of the software) in this report was ambitious – how best to report the results of an uncalibrated model. However the project team felt sufficiently confident in the quality and utility of the two component models, to proceed with the analysis described in Section 4. This was designed to draw together previous studies and demonstrate the evolution in catchment water quality modelling.

It is critical to understand the sources, connectivity and temporal dynamics of material fluxes as they move through a catchment – connecting land management to water quality. Having this operationalised within Australia's national hydrological modelling platform (eWater's Source) provides researchers, planners and catchment managers with an integrated tool to explore the impacts on the quality of receiving waters of catchment dynamics, such as gully and riparian management, urban and agricultural intensification, and environmental flows.

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Appendix A Constituent Sources

A.1 Overview

Two new pieces of functionality have been added to the constituents system of Source.

The first extends the granularity at which a user can model constituent generation and filtering. This is achieved by permitting more than one model to be used for generation or filtering on a given functional unit for a given constituent. In the past a user could only define one model for say functional unit 'FU2' - constituent 'TSS'. This is where the idea of 'constituent sources' came in. The user can now define multiple constituent sources, for example 'Hill slope' and 'Gully'. This means they could define a model for FU2 - TSS - Hill slope and another for FU2 - TSS - Gully. Typically each source would contain both a generation and filter model (like the old system) which would work together, the generation model passing its constituent load to the filter model for filtering with the output from the filter models being summed across all constituent sources for the functional unit.

The second new piece of functionality allows constituent generation / filter models to contain parameters which depend on a parameter from another generation / filter model. The concept is similar to that of functions whereby a parameter can be set from elsewhere in the system. Functions cannot be used here because the function manager is unable to influence the run order of models in a functional unit. So instead we have a simple parameter linking tool which allows a user to connect one parameter on one constituent model to another parameter on another. The model parameter which is to be written to must have been compiled with metadata indicating that its value should come from another constituent model's parameter. The linkage procedure and an example are outlined below.

A.2 Editing, adding and removing Constituent Sources

The first step when beginning to use constituent sources is to add additional sources to the constituent source list. By default a single source has automatically been added when the scenario was created called "Default". The screen to add/remove additional sources is found on the "Constituents Configuration" screen, accessed through the main menu "Edit -> Constituents..." (Figure 18).

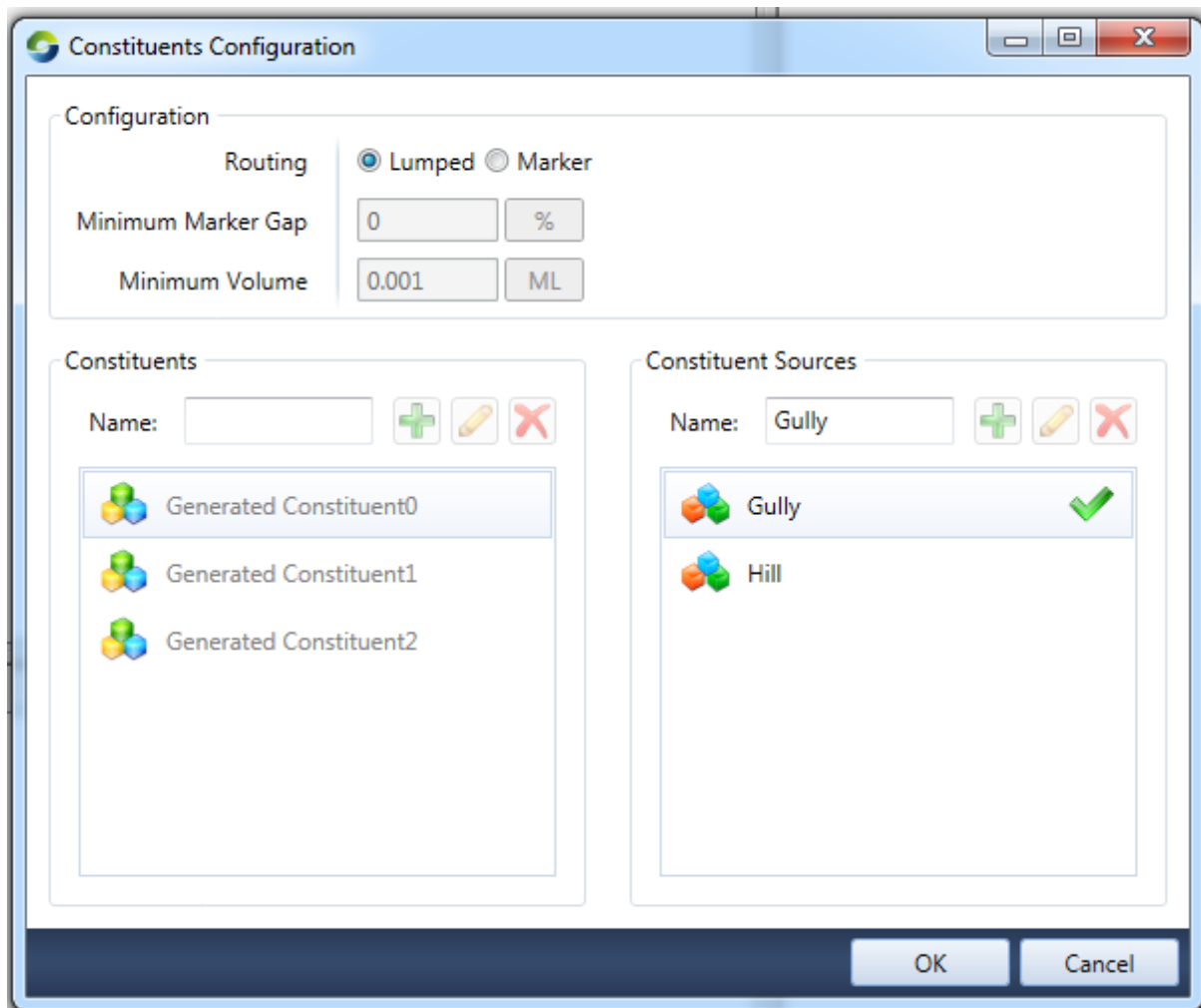


Figure 18, Constituents Configuration screen (Constituent Sources editor on right)

Here we see the constituent sources editor control on the right of the dialog. It shows two sources named “Gully” and “Hill”. “Gully” has a green tick beside it because it is the default source. The default source cannot be deleted and is the source that is automatically used by various editing/configuration tools when no other is specified or where the tool is unaware of constituent sources. Such tools were designed when each FU only had one model per constituent and do not understand that there is now potentially more, in these cases they are directed to simply edit/configure the default source’s models. The default constituent source can be changed by right clicking the source you want to be the new default and selecting “Set as Default”.

A.3 Editing, adding and removing Constituent Sources from Functional Units

Constituent generation and filter models are configured in the “Constituent Model Configuration” dialog access through the main menu “Edit -> Constituent Models...”.

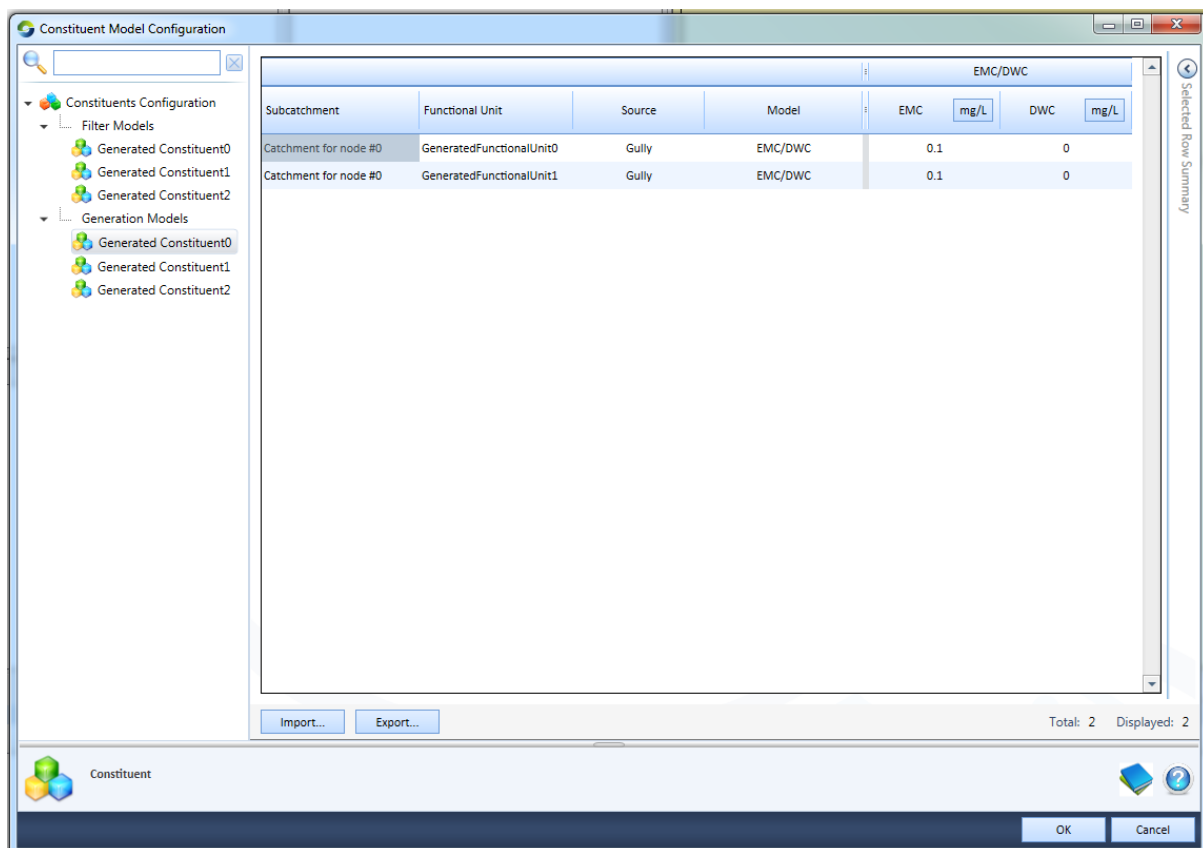


Figure 19, Constituent Model Configuration screen

Figure 19 shows the constituent generation models for all functional units and constituent sources for the constituent called “Generated Constituent0”. As can be seen in the data grid on the right, the first four columns are; Sub-catchment, Functional Unit, Source and Model. Previously this data grid contained only three primary columns, with the new system having added the Source column. This new column contains cells with a drop down list populated with all of the constituent sources that were defined as shown in Figure 18. This is one method by which the user can edit the constituent source assigned to a model. The remainder of the columns operate as before with the exception of the model linkage column which will be covered later in the document.

The user has the ability to assign the same constituent source more than once for a given FU. This operation is invalid and will result in an error message being shown at the top of the screen when the user attempts to click the ‘OK’ button. They will need to fix the issue before being able to proceed or select ‘Cancel’ and lose any changes made.

To assign a new constituent source to a FU, select the constituent for which you wish to add the constituent source in the tree view on the left and the FUs corresponding row in the data grid on the right (Figure 20). It does not matter whether you are in the generation of filter model data grid, as any additions / removals are automatically applied to both such that every constituent source has a corresponding generation and filter model placeholder.

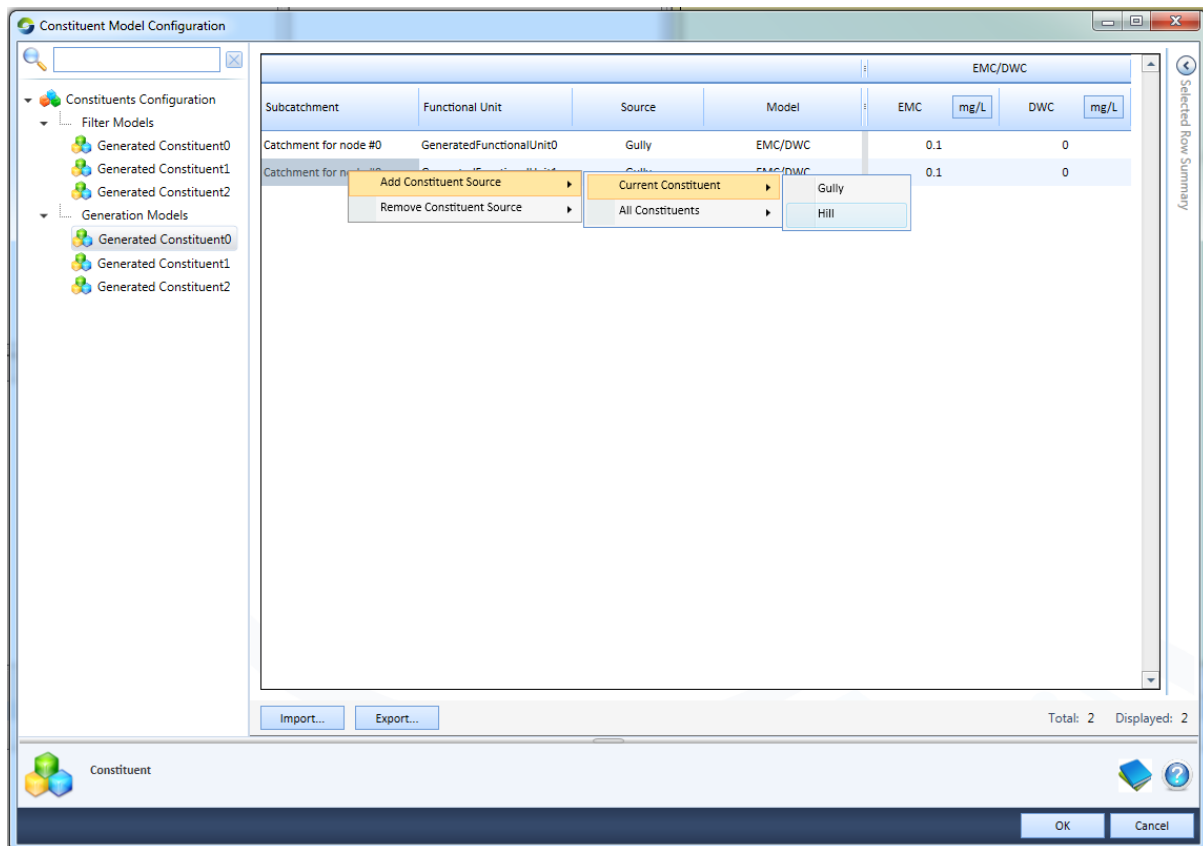


Figure 20, Assigning a new Constituent Source to a Constituent / FU

With the row selected, right click. Select “Add Constituent Source -> Current Constituent -> x” selecting the desired constituent source in place of x. This will add a new row to the data grid allowing the assignment and parameterisation of a new constituent generation or filter model for the selected Constituent / FU (Figure 21).

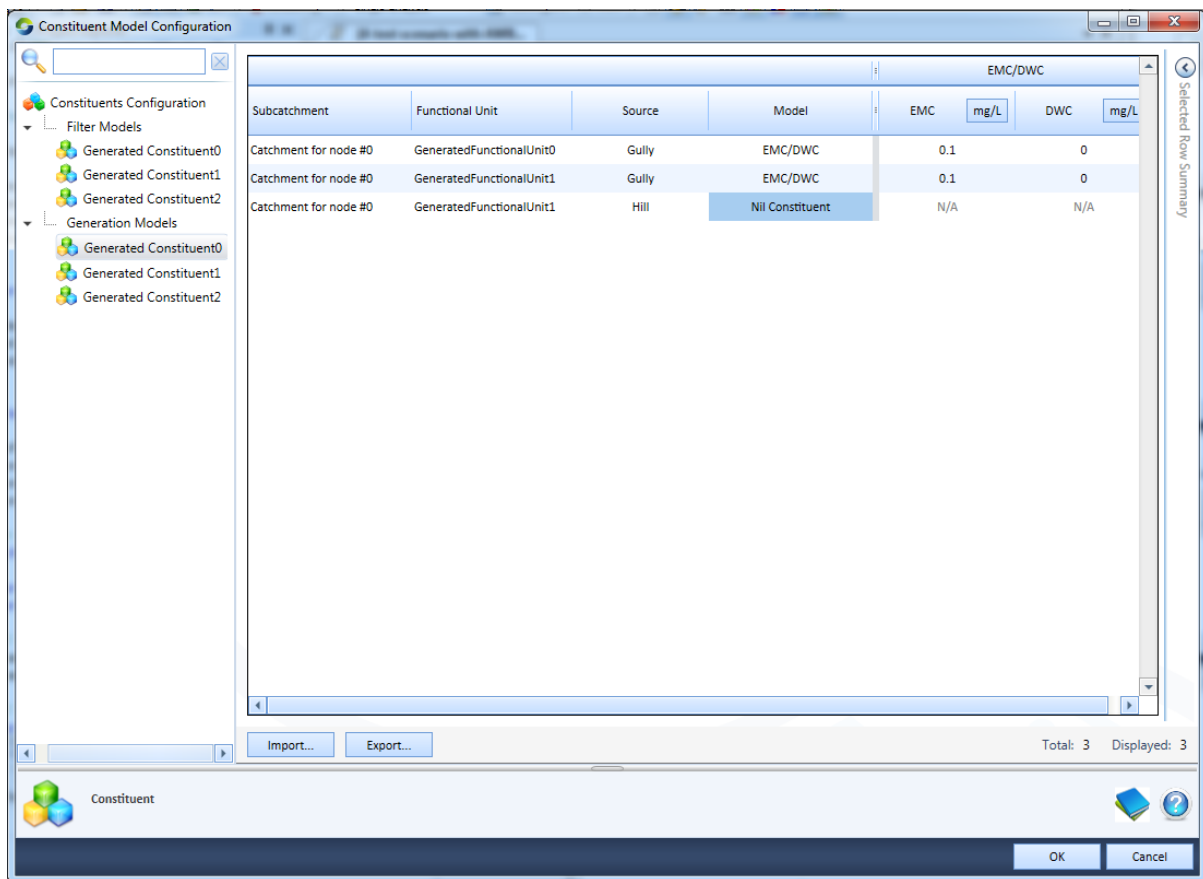


Figure 21, Shows two Constituent Sources for FU1. Gully with an EMC/DWC model and Hill with none

The process to un-assign a constituent source from a FU is almost identical to that of adding one; simply select the row and right click and instead of selecting “Add Constituent Source”, select “Remove Constituent Source”. At least one constituent source must exist at all times, so if the user attempts to remove all sources from a FU, they will all be removed and a new source (the default source) will be automatically added again.

The system also allows for bulk assignments to be made. You will have noticed that when right clicking on a row and nominating to either “Add” or “Remove” a constituent source, two options appear on the next menu. The first (and the one we selected above) is “Current Constituent”. This applies the “Add” or “Remove” operation just to the constituent selected on the tree view on the left. The second option is “All Constituents”. This option performs the “Add” or “Remove” to all constituents regardless of which is selected in the tree view.

Another powerful way of bulk adding or removing constituent sources is to select multiple rows in the data grid which correspond to different FUs. Selecting multiple FUs before right clicking performs the selected operation on all of those FUs in one hit. Selecting all of the desired rows in one go will become more difficult the larger the scenario. To get around this, the user can use the column filtering functionality of the data grid to trim the number of rows down to a more manageable number or they can break the changes down into several smaller changes.

A.4 Constituent model linking

Constituent generation and filter models may require one or more of their parameters to come from another generation or filter model on each time step. Although rare, these cases do exist and must be dealt with. At the moment only one such model exists in the core framework, the Nutrient Delivery Ratio (NDR) filter model. Each NDR model depends on the input to the Sediment Delivery Ratio (SDR) filter model. For a given functional unit and constituent source, the correct configuration of these filter models would be to assign one SDR to the sediment constituent, and one NDR to each other appropriate constituent. The NDR model has a parameter which it expects will be set to the same value as an input to the SDR. A linkage would then be created between the ‘quick flow in’ parameter on the SDR and the ‘quick flow sediment in’ parameter on the NDRs. The linkage system would, at runtime, ensure that the SDR has run before the NDRs, ensuring the correct flow of data at the right point in time. The system is designed to detect circular dependencies and force the user to remedy their defined linkages before being able to proceed.

The NDR parameter is marked up with a special attribute tag that tells the system to create a custom column in the data grid as shown in Figure 22.

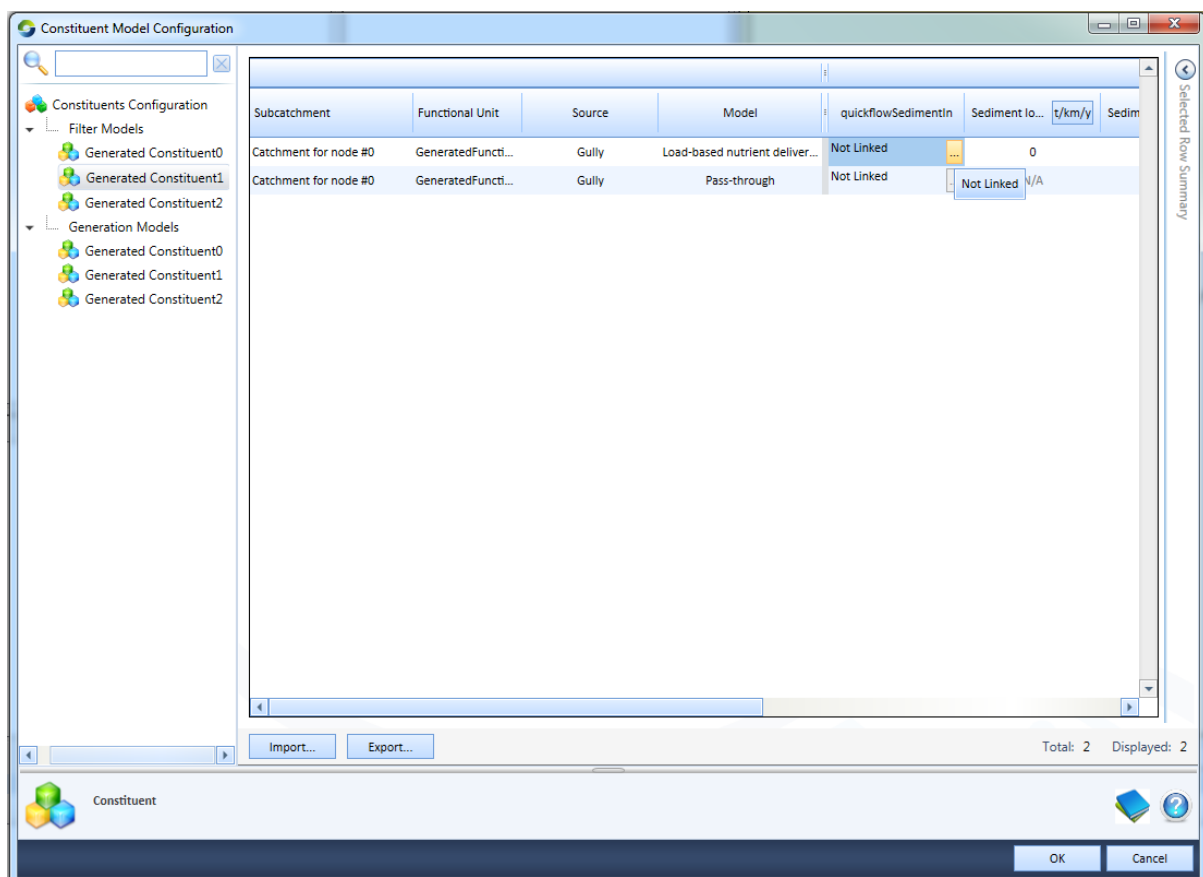


Figure 22, Shows the linkage column “quickflowSedimentIn” for the NDR filter model w/tooltip shown

By default, an undefined linkage show the text “Not Linked”. To link a parameter, click on the “...” button in the cell. Doing so launches the “Define Constituent Model Linkage” editor (Figure 23). This editor permits the user to specify where the value which is to be set on the

selected parameter comes from. They get to choose a parameter from any model, generation or filter, which exists in the same FU.

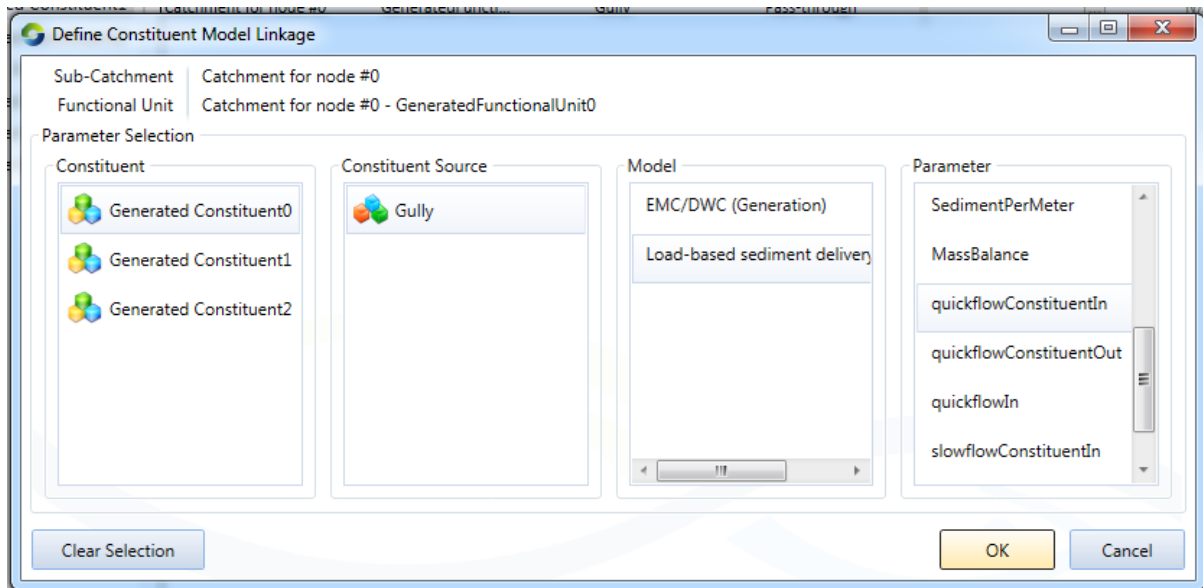


Figure 23, Define Constituent Model Linkage dialog

To make a linkage, the user selects the constituent, constituent source, model and finally the parameter on the model they want to get the value from. If no linkage is required, click the “Clear Selection” button to clear the linkage.

The user may have linked a parameter to another parameter on a model which may get de-selected on the main data grid prior to clicking “OK”. In that case, because the source of the linkage value no longer exists, an error message is presented and the user is unable to proceed until the issue is remedied.

A.5 Constituent model configuration import/export and copy/paste

The importing, exporting, copy and paste functionality on the data grids is almost unchanged from the old system. Two important changes were introduced to deal with the constituent sources and model parameter linkages.

When importing into the data grid, the number of rows in the data grid and in the csv file must match prior to importing the csv. This is a hangover from the old system in which the number of rows was much more static and would not typically change. The new system is not yet capable of dynamically varying the number of rows to suit the number of rows in the csv file upon the importation of csv. This issue *may* be addressed in the future.

When the value of a linkage cell is imported / pasted in, the linkage may not be valid at the time of importation / pasting. An example of this temporary invalidity would be a case where several data grids worth of values (several csv’s) needs to be imported, one after the other. The first csv of a data grid may contain a linkage to a model which does not exist yet because that model type is yet to be imported via the second csv of another data grid. In this case, the linkage is pending validation. It will remain pending until one of two things

happen. The first is that the user imports the second csv, creating the expected model type for the linkage to connect to and the situation is resolved. The second is that the user attempts to edit the linkage by clicking the “...” button before the second csv is imported. If this happens the user is presented with a question bar at the top of the Define Constituent Model Linkage dialog. They can choose to keep the pending linkage and close the dialog, or throw away the linkage and define a new one. All pending linkages will be thrown away and revert to “Not Linked” upon the clicking of the “OK” button on the main Constituent Model Configuration screen.

Appendix B Source hydrological model calibration

The rainfall-runoff model used in MLR is SIMHYD. Its parameters and their descriptions are listed in Table 12. Table 13 then details the values that were used for these parameters in each of the subcatchments above Houlgraves Weir gauging station. The derivation of these posterior distributions is described in Kuhnert et al. (2015). Briefly, they are the product of a computational Bayesian statistical method using a Markov chain Monte Carlo (MCMC), specifically the Particle Marginal Metropolis-Hastings (PMMH) algorithm, implemented using the LibBi modelling language (www.libbi.org), on CSIRO's Bragg GPU cluster. The Bayesian Hierarchical Model (BHM) applied consists of three component models: (i) a parameter model; (ii) a process model; and (iii) a data model; it therefore integrates the uncertainty associated with measurement error, model structural error and parameter uncertainty. These are the values used for the multi-region run. For the single-region run, these values were replaced with those for Onkaparinga River at Houlgraves Weir (A5030504).

Table 12, SIMHYD parameters and their description

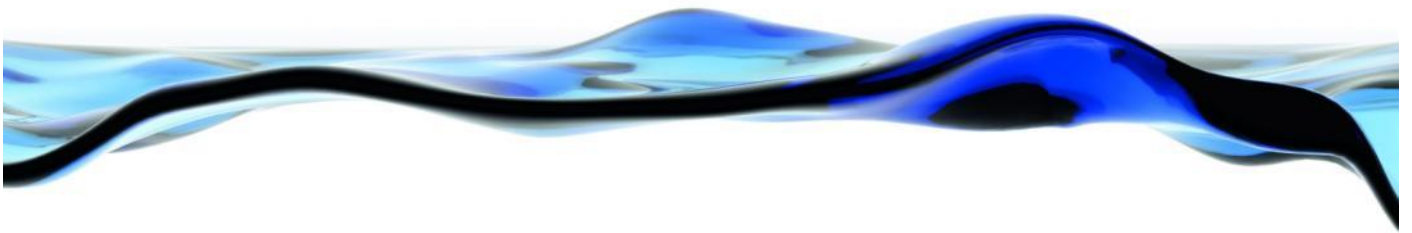
SIMHYD Parameter	Parameter Description
BFC	Baseflow Coefficient
ImpT	Impervious Threshold
InfC	Infiltration Coefficient
InfS	Infiltration Shape
IntC	Interflow Coefficient
RISC	Rainfall Interception Store Capacity
RC	Recharge Coefficient
SMSC	Soil Moisture Store Capacity
PF	Pervious Fraction

Table 13, SIMHYD parameter values for subcatchments above Houlgraves Weir

Parameter	Prior	Posterior Mean	Posterior Std. Dev.
Scott Creek (A5030502)			
BFC	Uniform(0.0, 1.0)	0.50946973	0.016528233
ImpT	Uniform(0.0, 5.0)	4.51530975	0.069255958
InfC	Uniform(0.0, 400.0)	368.84816229	6.978554521
InfS	Uniform(0.0, 10.0)	2.54062924	0.171095156
IntC	Uniform(0.0, 1.0)	0.01044187	0.009040683

Parameter	Prior	Posterior Mean	Posterior Std. Dev.
RISC	Uniform(0.0, 5.0)	2.98077001	0.087073120
RC	Uniform(0.0, 1.0)	0.53721164	0.034862902
SMSC	Uniform(1.0, 500.0)	441.85681082	5.687646120
PF	Fixed at 0.9882	NA	NA
σ_Y^2	Uniform(0.0, 50.0)	0.08196454	0.003346443
γ	Fixed at 0.568	NA	NA
Onkaparinga River at Houlgraves (A5030504)			
BFC	Uniform(0.0, 1.0)	0.2208156	0.014819471
ImpT	Uniform(0.0, 5.0)	1.5266724	0.051301204
InfC	Uniform(0.0, 400.0)	310.8484224	2.540927433
InfS	Uniform(0.0, 10.0)	7.7569705	0.071991030
IntC	Uniform(0.0, 1.0)	0.5937983	0.020168979
RISC	Uniform(0.0, 5.0)	4.5586270	0.060481276
RC	Uniform(0.0, 1.0)	0.9151727	0.003087179
SMSC	Uniform(1.0, 500.0)	480.6725026	0.235648616
PF	Fixed at 0.9446	NA	NA
σ_Y^2	Uniform(0.0, 50.0)	3.9213502	0.013379365
γ	Fixed at 0.296	NA	NA
Echunga Creek (A5030506)			
BFC	Uniform(0.0, 1.0)	0.2631035	0.009357879
ImpT	Uniform(0.0, 5.0)	4.5997346	0.046183530
InfC	Uniform(0.0, 400.0)	263.6316217	2.232659643
InfS	Uniform(0.0, 10.0)	3.6891630	0.085851710
IntC	Uniform(0.0, 1.0)	0.1931145	0.005312499
RISC	Uniform(0.0, 5.0)	2.1552390	0.030487029
RC	Uniform(0.0, 1.0)	0.4142936	0.016476717
SMSC	Uniform(1.0, 500.0)	311.4975548	7.236706408
PF	Fixed at 0.9880	NA	NA
σ_Y^2	Uniform(0.0, 50.0)	Uniform(0.0, 50.0)	Uniform(0.0, 50.0)
γ	0.3264762	0.3264762	0.3264762
Lenswood Creek (A5030507)			
BFC	Uniform(0.0, 1.0)	0.7684376	0.011275820
ImpT	Uniform(0.0, 5.0)	3.6071693	0.045883147

Parameter	Prior	Posterior Mean	Posterior Std. Dev.
InfC	Uniform(0.0, 400.0)	271.7770589	1.861055664
InfS	Uniform(0.0, 10.0)	1.9393779	0.101378632
IntC	Uniform(0.0, 1.0)	0.1112417	0.031033526
RISC	Uniform(0.0, 5.0)	2.7415063	0.038750480
RC	Uniform(0.0, 1.0)	0.7988820	0.024083771
SMSC	Uniform(1.0, 500.0)	495.4780496	4.620941444
PF	Fixed at 0.9872	NA	NA
σ_Y^2	Uniform(0.0, 50.0)	Uniform(0.0, 50.0)	Uniform(0.0, 50.0)
γ	0.5469393	0.5469393	0.5469393
Aldgate Creek (A5030509)			
BFC	Uniform(0.0, 1.0)	0.2775155	0.003277401
ImpT	Uniform(0.0, 5.0)	1.4912742	0.016705611
InfC	Uniform(0.0, 400.0)	385.4460279	1.049049064
InfS	Uniform(0.0, 10.0)	4.8779148	0.020440462
IntC	Uniform(0.0, 1.0)	0.9251572	0.002706702
RISC	Uniform(0.0, 5.0)	3.1364001	0.011110353
RC	Uniform(0.0, 1.0)	0.1422747	0.003133744
SMSC	Uniform(1.0, 500.0)	368.2218761	1.764740494
PF	Fixed at 0.4562	NA	NA
σ_Y^2	Uniform(0.0, 50.0)	Uniform(0.0, 50.0)	Uniform(0.0, 50.0)
γ	0.8228833	0.8228833	0.8228833
Cox Creek at Uraidla (A5030526)			
BFC	Uniform(0.0, 1.0)	0.2260891	0.005002859
ImpT	Uniform(0.0, 5.0)	2.7424336	0.019565708
InfC	Uniform(0.0, 400.0)	370.4920976	1.547506409
InfS	Uniform(0.0, 10.0)	2.4356425	0.060775594
IntC	Uniform(0.0, 1.0)	0.1360886	0.009318794
RISC	Uniform(0.0, 5.0)	0.2541457	0.068799807
RC	Uniform(0.0, 1.0)	0.4402221	0.013047989
SMSC	Uniform(1.0, 500.0)	307.4087414	1.936014354
PF	Fixed at 0.9106	NA	NA
σ_Y^2	Uniform(0.0, 50.0)	Uniform(0.0, 50.0)	Uniform(0.0, 50.0)
γ	0.1354553	0.1354553	0.1354553



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